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Koutsouras, Dimitris A.

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NAVAL POSTGRADUATE SCHOOL
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THESIS

PERFORMANCE STUDY OF A UNIPOLE
ANTENNA WITH CONVENTIONAL AND ELEVATED
RADIAL WIRE GROUND SCREENS

by

Dimitris A. Koutsouras

December 1987

Thesis Advisor: R.W. Adler

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Performance Study of a Unipole Antenna with Conventional and Elevated Radial Wire Ground Screens

by

Dimitris A. Koutsouras
Lieutenant, Hellenic Navy
B.S., Hellenic Naval Academy, 1979

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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ABSTRACT

The advantages of using elevated radial wire ground screens with vertical monopole antennas for MF and HF broadcast have recently been reported. This study extends the concept to the folded unipole antenna and compares the performance of a folded unipole with elevated radials to that of monopoles operating with both elevated and conventional buried radial wire ground screens. The unipole's performance with 2,3 and 4 elevated radials, is within 2% of that for a standard monopole using 120 buried radial wires.

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I. INTRODUCTION

A. BROADCAST ANTENNAS

Most of the broadcast stations in the medium frequency range use vertical radiators as antennas. The height of the radiator varies from one-sixth to five-eighths wavelength [Ref.1]. The economic considerations and the desired characteristics determine the height of the antenna for a particular AM broadcast station. Generally the height of the antenna is chosen to be one-quarter wavelength. The current return path includes the space and the ground. Due to high current densities in the ground, the conductivity of the ground is raised by incorporating a radial wire buried ground system. The typical ground system consists of 120 quarter-wave length long radial wires buried about 4 to 6 inches below the surface of the earth. The radiators can be either insulated at the base or grounded with shunt excitation.

The folded-unipole antenna is a modification of a standard shunt-fed system [Ref.2]. This antenna has wires (one or more can be used) attached to the tower at a pre-determined height, supported by stand-off insulators, and run parallel to the sides of the tower to its base. The tower is grounded at its base. These folds, or wires, are joined together at the base and driven at this point through

an impedance matching network. The folded unipole antenna was introduced in the late 1950's for standard broadcast stations and today over 1,200 licensed stations use the folded unipole method of feed. Figure 1.1 shows a typical folded unipole antenna.

The folded unipole antenna has significant advantages over both the series fed vertical or top-loaded antenna. The more salient advantages are:

* Greater radiation resistance.
* Greater system bandwidth.
* No base insulator
* More stable in inclement weather (but not with heavy icing)
* Easier multiple frequency operation (simple multiplexer circuitry because antenna structure provides some off-frequency isolation).
* Base impedance can be easily varied.

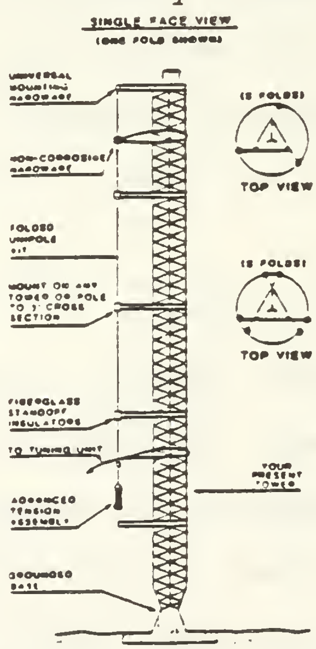

Figure 1.1 Typical Folded Unipole Antenna

B. INTERESTING ANTENNA PARAMETERS

1. Input impedance

Input Impedance is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals" [Ref.3]. The input impedance is composed of real and imaginary parts.

$$Z_{in} = R_{in} + jX_{in}$$

where

Z_{in} = antenna impedance at its terminals

R_{in} = antenna resistance at its terminals

X_{in} = antenna reactance at its terminals.

In general the resistive part consist of two components

$$R_{in} = R_r + R_L$$

where

R_r = radiation resistance of the antenna

R_L = loss resistance of the antenna.

Radiation resistance R_r is a form of dissipation and represents power that leaves the antenna as radiation and never returns. Loss resistance R_L represents power dissipated on the antenna structure and associated hardware as heating losses and power dissipated in the ground because of the ground-system losses. These losses are equivalent to the power dissipated in a resistor in series with the antenna impedance. Input reactance, X_{in}, represents power stored in the near field of the antenna. The antenna

impedance is important to the transfer of power from a transmitter to an antenna or from an antenna to a receiver. For maximum transfer power from a receiving antenna, the antenna impedance should be a conjugate match to the receiver impedance (equal resistances, equal magnitude and opposite sign reactances). Usually the transmitter or receiver has a real impedance so it is necessary to "tune out" the antenna reactance with a matching network of variable inductances and capacitances adjusted to cancel antenna reactance.

2. Average Power Gain

Another useful parameter describing the performance of an antenna is the gain. It is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. A common criterion applied to antenna computer models is to calculate the average power gain. It is obtained by integrating the radiation power density to find the total radiated power, then comparing that to the total input power at the feed points. These should be equal for a valid solution. The average power gain provides a check on the accuracy of the computed input impedance. It should be equal to 2 over a perfectly conducting ground and equal to 1 in free space. For engineering purposes, values of average power gain within ±10% of ideal are considered acceptable.

C. SCOPE OF THE THESIS

In this thesis we will investigate the replacement of the ground system for an antenna which consists of 120 buried radial wires, with a small number of radials, only four, and not buried but elevated above ground. This model of antenna (4 elevated radial wires) is cheaper and has almost the same performance as the one with 120 buried radials. The research will be done at the following practical design cases:

1. The input impedance of a 75 meter folded unipole with three fold wires and four radial wires extended from the base of the unipole, spaced at an angle of 90^0, at elevations from 1 to 15 meters above a finite ground plane.

2. The input impedance of a 75 meter monopole with four radial wires extended from the base at an angle of 90^0, at elevations from 1 to 15 meters from a finite ground.

3. A comparison of radiation patterns of a 75 meter folded unipole with four, three, two and one radial wires at elevations from 1 to 15 meters.

4. Effect on radiation efficiency of elevated vs buried radial wire ground screens for monopoles.

5. A comparison of radiation efficiency of elevated unipoles vs a monopole with 120 buried radial wires.

II. NUMERICAL ELECTROMAGNETIC CODE

A. INTRODUCTION

The Numerical Electromagnetic Code (NEC) [Ref.4], is an advanced version of the Antenna Modeling Program (AMP) and was developed by the Lawrence Livermore Laboratory, Livermore California, under the sponsorship of the Naval Ocean Systems Center and the Air Force Weapons Laboratory.

NEC is based on the numerical solution of integral equations (I.E) for currents induced on arbitrary structures by sources or incident fields. In Appendix A, there is a brief description of the I.E. The arbitrary structure can include either wire antennas or closed surface metal structures and can be modeled over a ground plane that may be either a perfect or imperfect conductor. The excitation of the structure can include a voltage source or an incident plane wave with either linear or elliptical polarization. A model may include nonradiating networks and transmission lines connecting parts of the structure, perfect or non-perfect conductors and lumped element loading.

The program can give outputs such as induced currents and charges, near and far zone electric and magnetic fields, impedance or admittance, input power or total radiation power, directive or power gain, antenna efficiency and radiated fields for plotting radiation patterns.

B. GUIDELINES FOR MODELING STRUCTURES

NEC requires that antennas or any other conducting objects must be modeled with strings of segments or patches which should follow the paths of conductors as closely as possible. Short straight segments are used for modeling wires and flat patches for modeling closed surfaces. In order to obtain the most accurate results, proper selection of segments and patches is essential. The more segments or patches used in a model the more accurate solution in general, but on the other hand the program run time increases rapidly as this number increases. Thus the number of segments and patches should be the minimum required for accuracy. Guidelines for choosing segments and patches are given below.

1. Wire Modeling Guidelines

A wire segment is defined by its radius and the coordinates of its start and end point. Figure 2.1 illustrates the wire segment parameters.

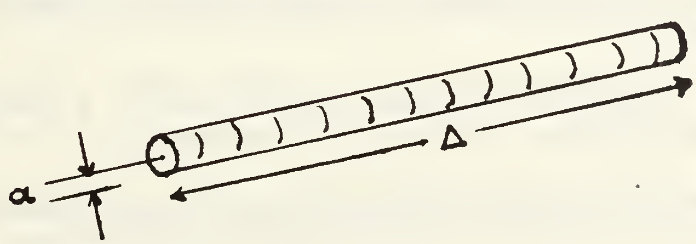

Figure 2.1. Wire Segment Parameters

Key parameter is segment length Δ relative to the wavelength, λ. The segment length Δ should be:

* less than about 0.1λ at the desired frequency;
* less than 0.05λ in critical regions of a model;
* not less than $10^{-3}\lambda$.

In some cases with long wires, segments longer than 0.1λ may be acceptable.

The wire radius, α, relative to wavelength is limited by the approximations used in the kernel of the electric field IE. There are two available approximations in NEC: the thin-wire kernel and the extended thin-wire kernel. A thin wire is one for which the radius is small compared to the wavelength. The accuracy of the solution is also dependent on Δ/α and in the case with a thin-wire kernel, Δ/α must be greater than about eight (8) in order to have errors less than 1%. Δ/α may be as small as 2 for the same accuracy when applying the extended thin-wire kernel.

Some guidelines for the segment model follow:

* Segments must connect each other at their ends.
* Segments (or patches) may not overlap.
* Between connected segments a large radius change may decrease accuracy.
* A segment is required at each point where a network connection or voltage source is located.
* The two segments on each side of a voltage source should be parallel and have the same length and radius.
* When wires are parallel and very close together, the segments should be aligned to avoid incorrect current

perturbations from offset match points and segment junctions.

* Parallel wires should be several radii apart.

2. Modeling Structures Over Ground

NEC provides several options for modeling an antenna over a ground plane.

a. **Model Over Perfect Ground**

For a perfectly conducting ground the program generates an image of the structure reflected in the ground plane. Structures may be close to the ground. For a horizontal wire,

$$\sqrt{h^2+\alpha^2} > 10^{-6}\,\lambda$$

where:

α=wire radius.

h=height of wire axis above the ground plane.

The height should be at least several times the radius for the thin-wire approximation to be valid. This method doubles the time to fill the interaction matrix.

b. **Model Over Finite Ground (Sommerfeld/Norton)**

A finite conducting ground for an antenna may be modeled with the Sommerfeld/Norton method. This method is available for wires only, uses the exact solution for the fields in the presence of ground, is accurate close to the ground and has the same height restriction for a horizontal wire as for a perfect ground.

This method requires an input file (FILE 21) containing the field values for the specific ground parameters and the desired frequency. This file may be saved and reused for problems having the same ground parameters and frequency.

C. NEC INPUT DATA CARDS

Data which describes structures and requests computation of structure characteristics are contained in files made up of card images. There are three types of "cards" and each type plays a specific role. These types are **Comment Cards, Geometry Cards** and **Program Control Cards**. In Appendix B there is a NEC input card summary.

III. COMPUTER MODELS - RESULTS

A. MONOPOLE WITH 120 BURIED RADIAL WIRES

In AM broadcasting the standard antenna is a quarter-wave monopole with 120 quarter-wave buried radial wires. The radial wire system raises the effective conductivity of the ground. All other antennas are compared to it. Figure 3.1 illustrates this monopole antenna.

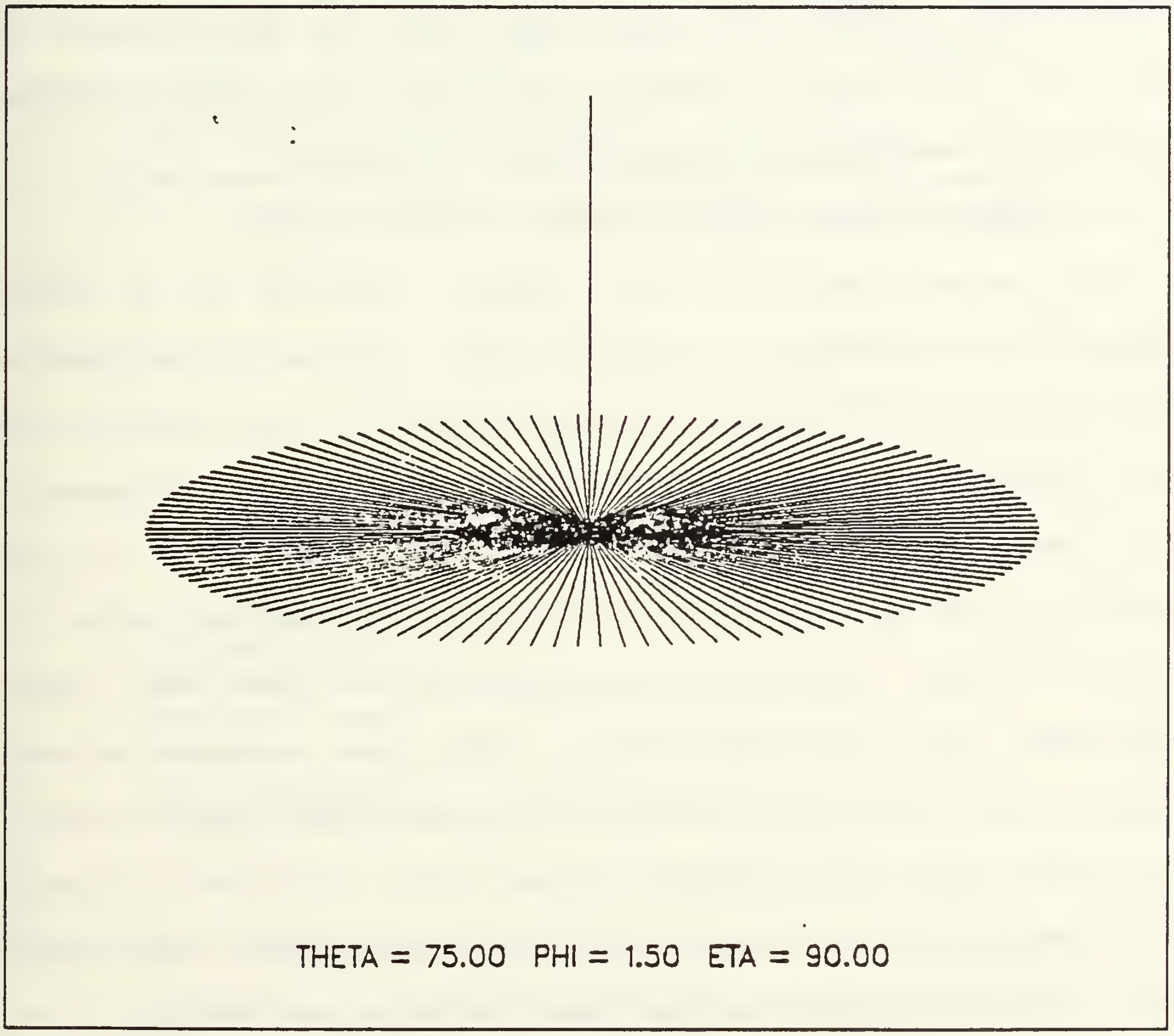

Figure 3.1 A Typical AM Broadcast Antenna

The data set used to model a typical AM broadcast antenna with 120 radial wires is given in Appendix D.6. The vertical radiation pattern as produced by NEC is shown in Figure 3.2.

The surface wave field strength of this antenna has a value of 289.3 mV/M/KW at a distance of one kilometer and the value of the space wave field strength is 239.9 mV/M/KW at the same distance. The input impedance is 39+j21.8 ohms. The folded unipole is an alternate solution for broadcasters looking for the same radiation performance as that of the above monopole and with all the unipole advantages mentioned in Chapter I.

B. 90 DEGREE FOLDED UNIPOLE WITH 4 RADIAL WIRES

The model used in this thesis consists of a tower (quarter-wave monopole) on the Z axis, mounted perpendicular to a finite ground plane with parameters = 0.01 mhos/M and =15 (typical ground constants), and operates at a frequency of 1 MHz (center of AM broadcast band). The radius of the tower is 3 mm and was used to simplify the computer model in order to save computational resources. If the true tower size were used, the run-time for this study would have been so high that very few cases could have been tried. Later, if needed, the more complete model using a cylindrical cage of 6 parallel wires [Ref.5:p.26] can be applied. The trends and features of the models here will apply to full size tower models also.

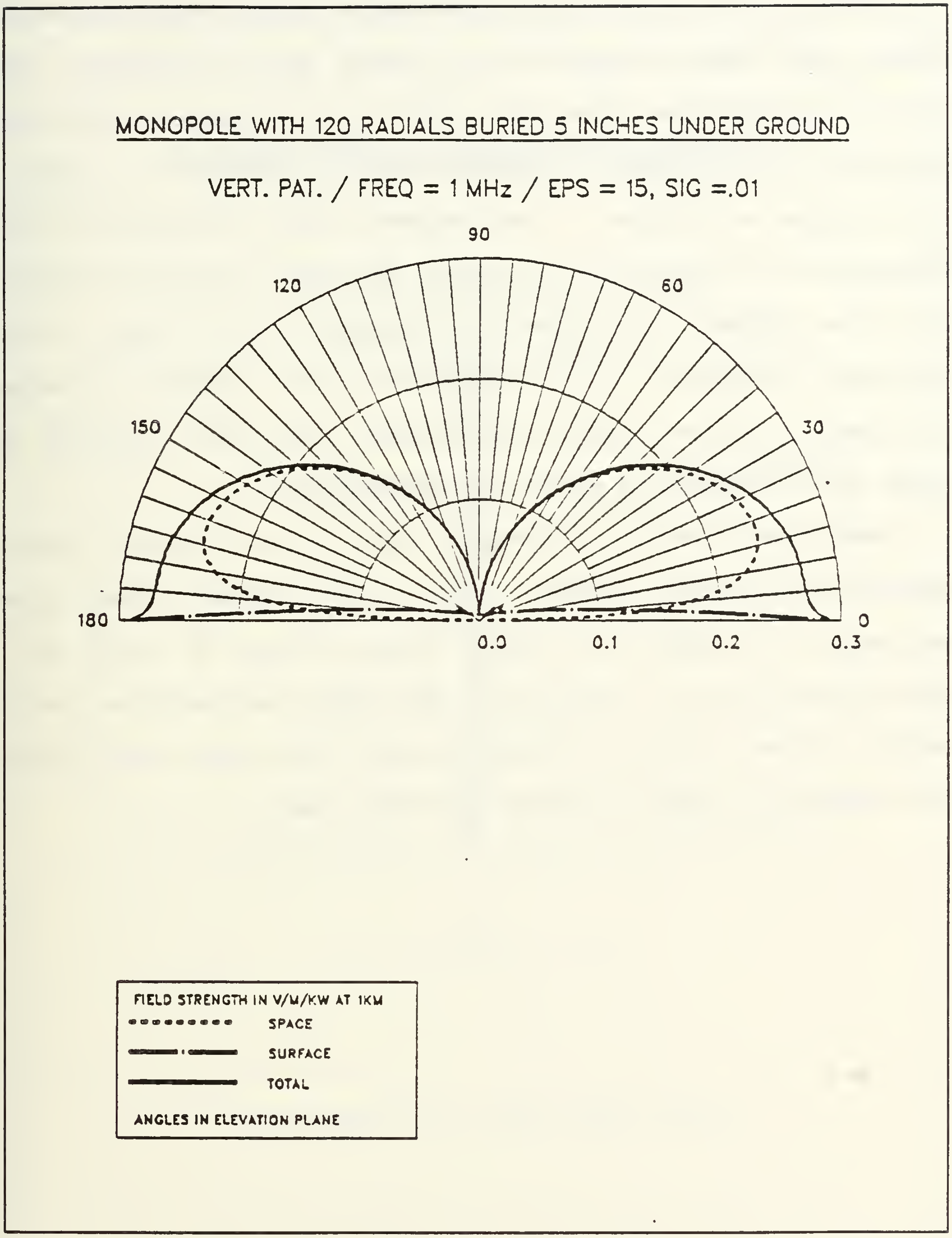

Figure 3.2 Radiation Pattern - Typical AM Broadcast Antenna

Three fold wires with the same radius are arranged around the tower, spaced at an angle of 120 degrees. The fold wire distance from the tower is 0.9 meters. The top bracket is at height 75 meters and the bottom at 1 meter. Four wires of radius 3 mm extend from the base of the monopole to a radius of 75 meters arranged around the tower like the spokes of a wheel and spaced at an angle of 90 degrees. Figure 3.3 illustrates this unipole antenna elevated 15 meters above the ground. The data set used to model this antenna is given in Appendix D.1.

When the antenna is elevated from 1 to 15 meters over a perfect reflecting ground plane, the average power gain decreases as Figure 3.4 shows, from a value of 1.941 at 1 meter elevation to a value of 1.881 when the elevation is 15 meters. These values of average power gain help verify that the numerical model is valid for this study.

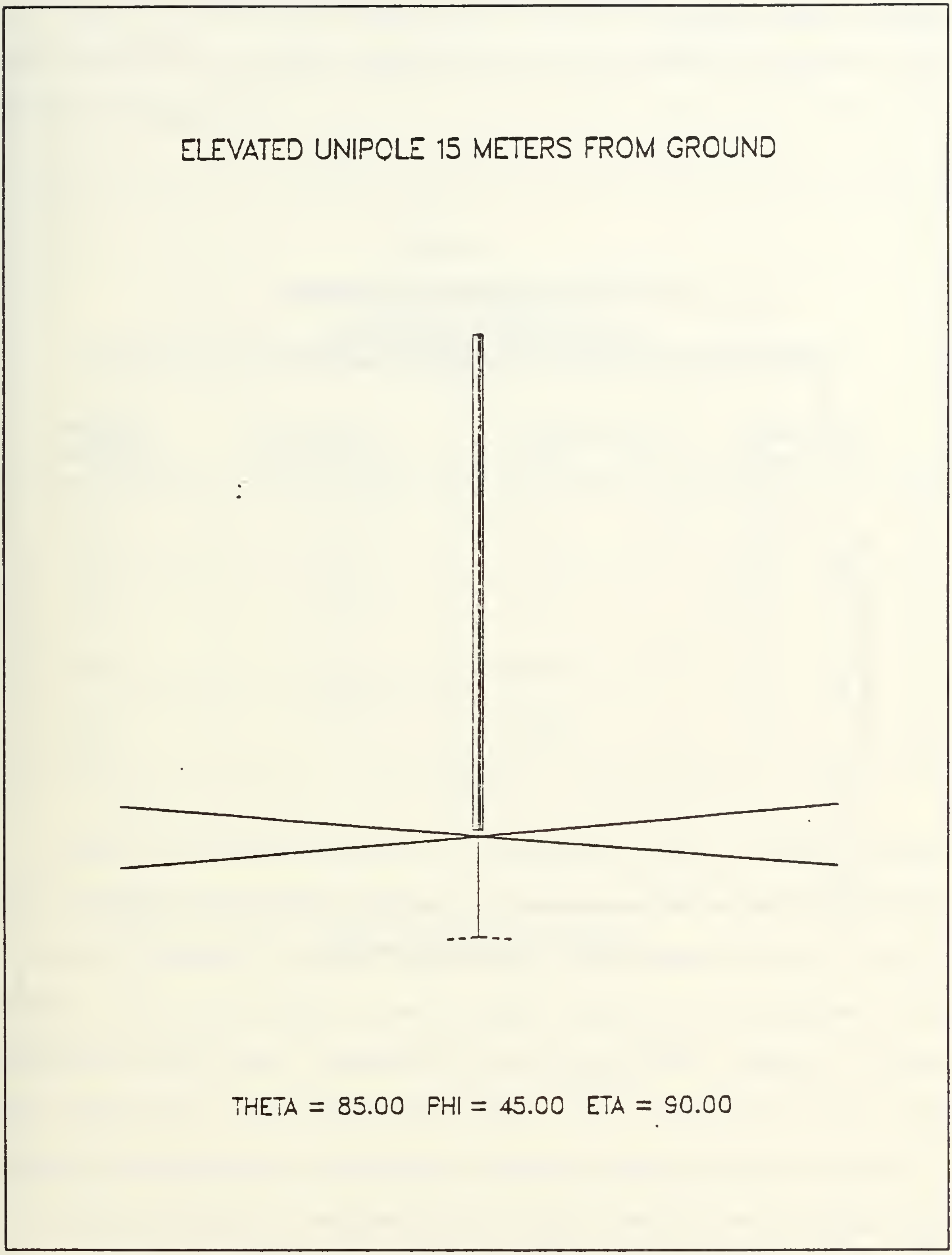

Figure 3.3 Folded Unipole Elevated 15 Meters Over Finite Ground

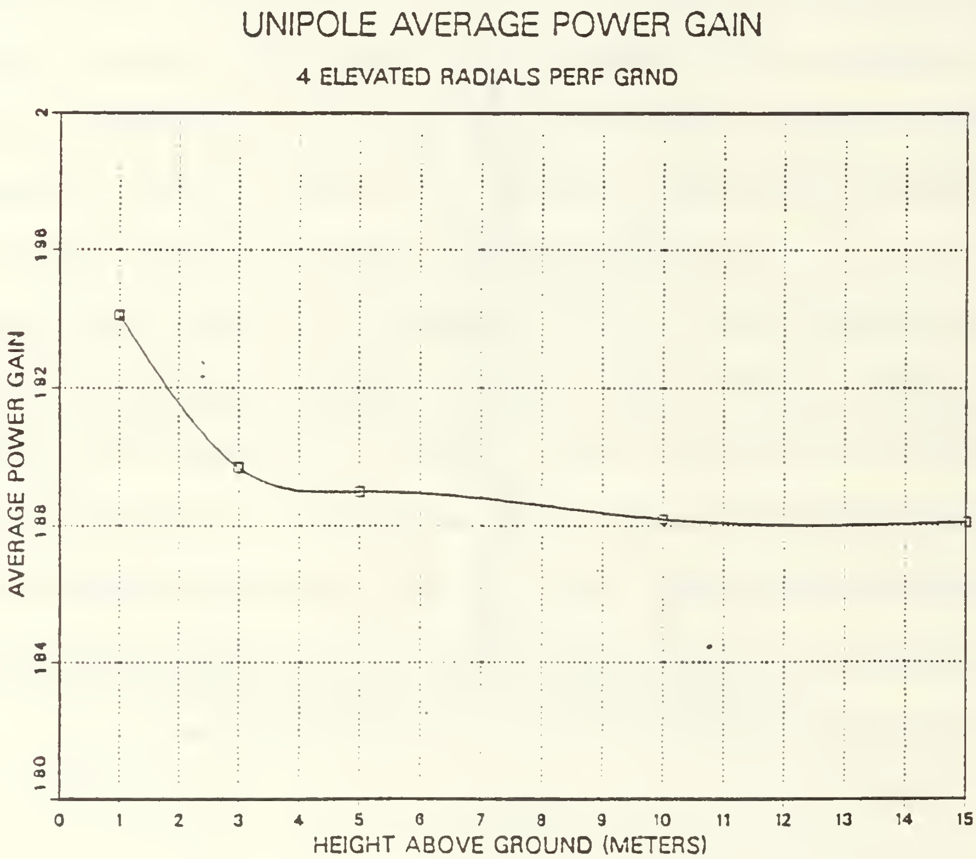

Figure 3.4 Folded Unipole Average Power Gain

Table 1 lists the variation of average power gain, input resistance and input reactance for different heights of 1 through 15 meters.

TABLE 1

90 DEG. UNIPOLE WITH FOUR 90 DEG. RADIALS
PERFECT GROUND
EFFECT ON AVERAGE POWER GAIN VARYING THE HEIGHT

Height Meters	Average Power Gain	Resistance Ohms	Reactance Ohms
1.0	1.941	214	133
3.0	1.897	214	115
5.0	1.890	211	102
10.0	1.882	201	80
15.0	1.881	192	66

When the folded unipole is elevated over a finite ground the surface wave field strength increases from 266.8 mV/M/KW to 288.3 mV/M/KW as the elevation increases from 1 to 15 meters. Also the space wave field strength increases with elevation from 220.7 mV/M/KW to 233.8 mV/M/KW. Table 2 lists the variation of surface and space wave field strength and input impedance for different heights above finite ground.

The radiation patterns of this model are shown in Figures C.2 through C.6 for different elevations, and are close to the pattern for the standard monopole with 120

buried radial wires. Thus, the small number of elevated radial wires makes this antenna cheaper and better for use in large city environments where adequate land space for a radial wire ground screen is not available.

TABLE 2

90 DEG. UNIPOLE WITH FOUR 90 DEG. RADIALS
FINITE GROUND
EFFECT ON GROUND AND SPACE WAVE FIELD VARYING HEIGHT

Height meters	Ground Wave Field Strength in mV/M/KW	Space Wave Field Strength in mV/M/KW	Impedance R Ohms	Impedance X Ohms
1.0	266.8	220.7	236.8	188.8
3.0	272.6	225.0	224.1	118.4
5.0	277.4	228.5	215.9	95.3
10.0	282.3	230.9	200.8	70.4
15.0	288.3	233.8	188.7	57.2

Figure 3.5 illustrates the field strength (surface and space wave) of this antenna and Figure 3.6 shows the impedance of the folded unipole over perfect and finite ground. Figure 3.6 shows that antenna input resistance decreases when the elevation increases. If antenna resistance decreases over lossy ground, one usually expects that ground losses are diminishing and are not adding as much loss resistance to antenna input resistance. In Figure 3.5 the surface wave field strength increases when the

elevation increases, so the power coupled into surface wave increases at expense of other power. Possibly the space wave power is dropping; this is seen to be the case when comparing the radiation patterns at heights of 1 and 15 meters (Figures 3.7 and 3.8).

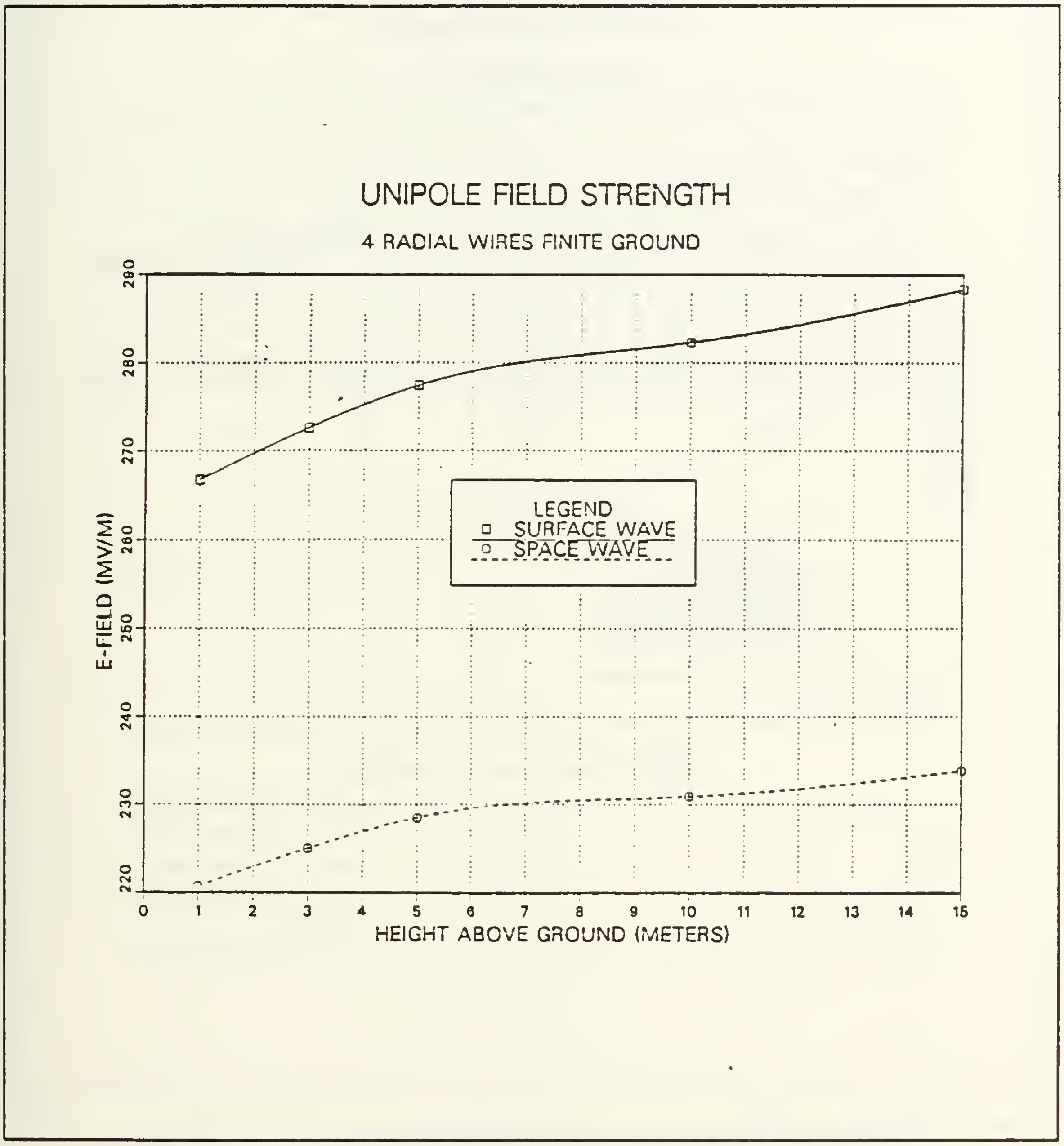

Figure 3.5 Folded Unipole Electric Field Strength

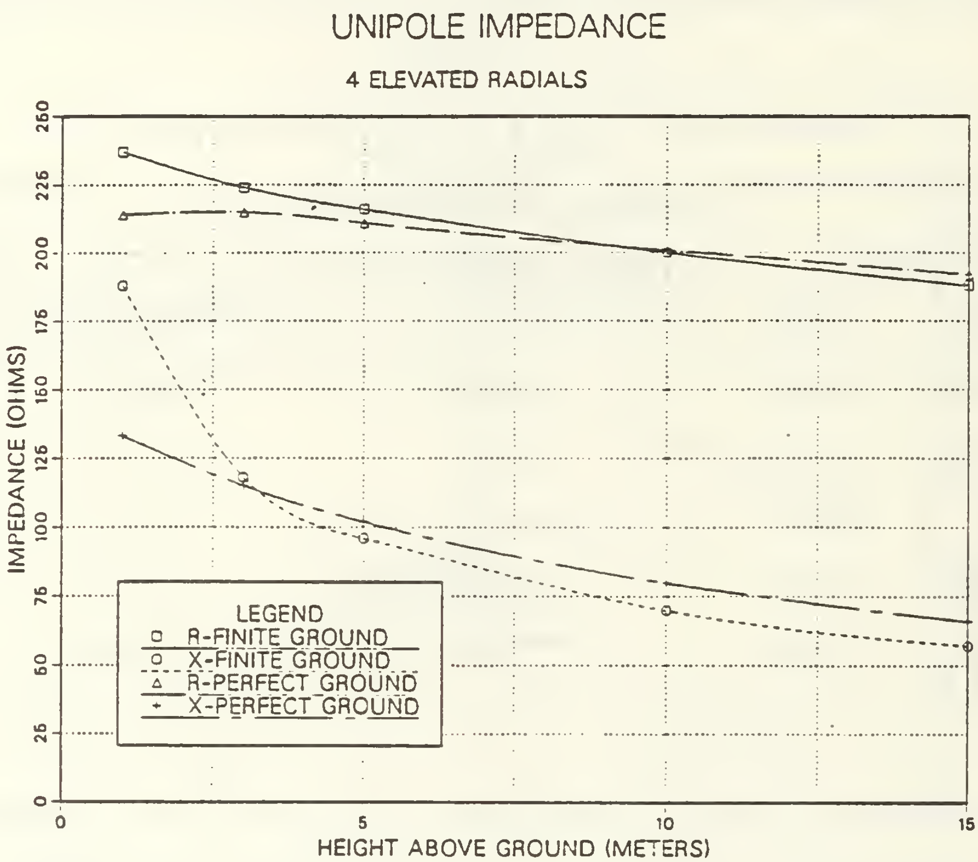

Figure 3.6 Folded Unipole Impedance Variation

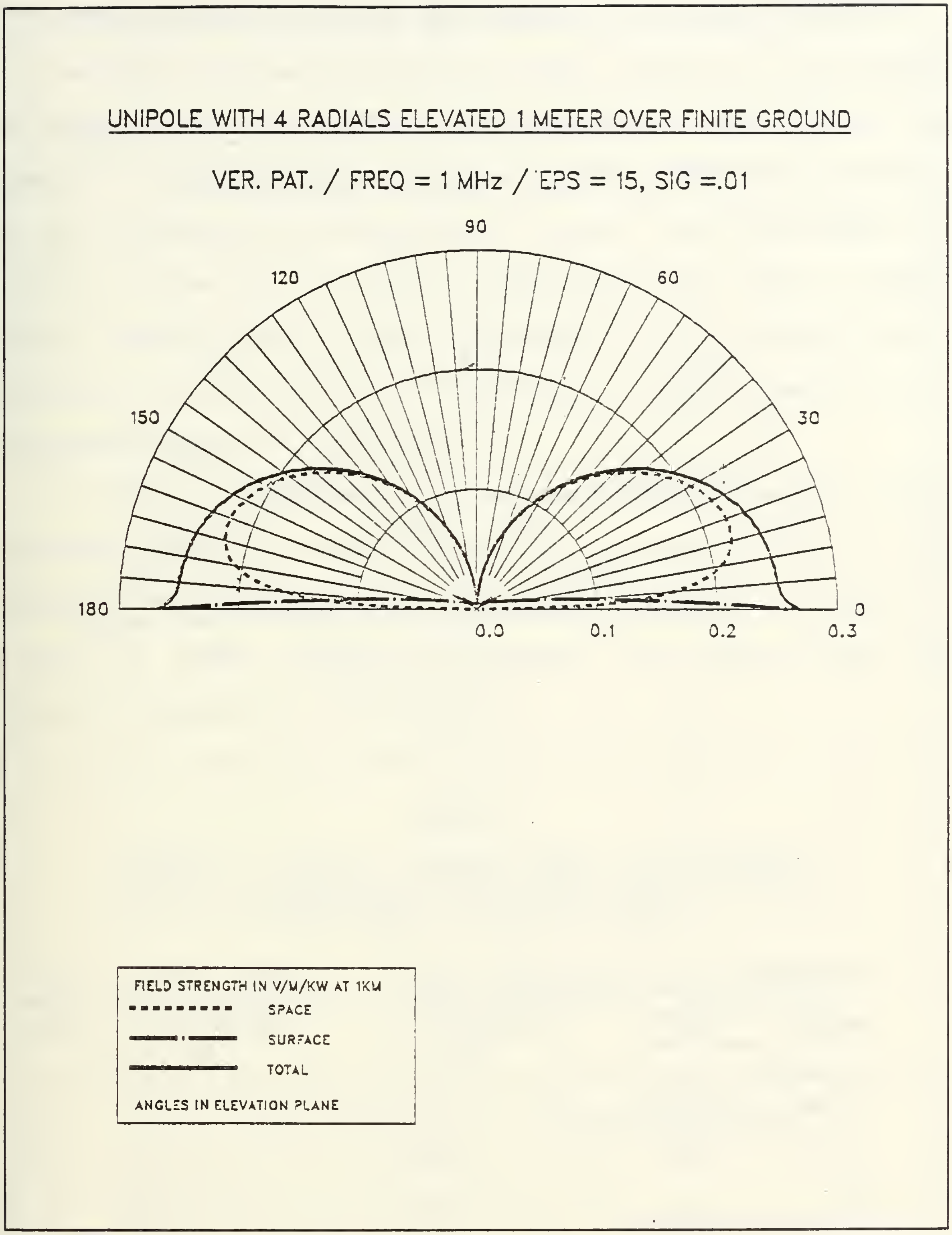

Figure 3.7 Radiation Pattern - Folded Unipole

Elevated 1 Meter Over Finite Ground

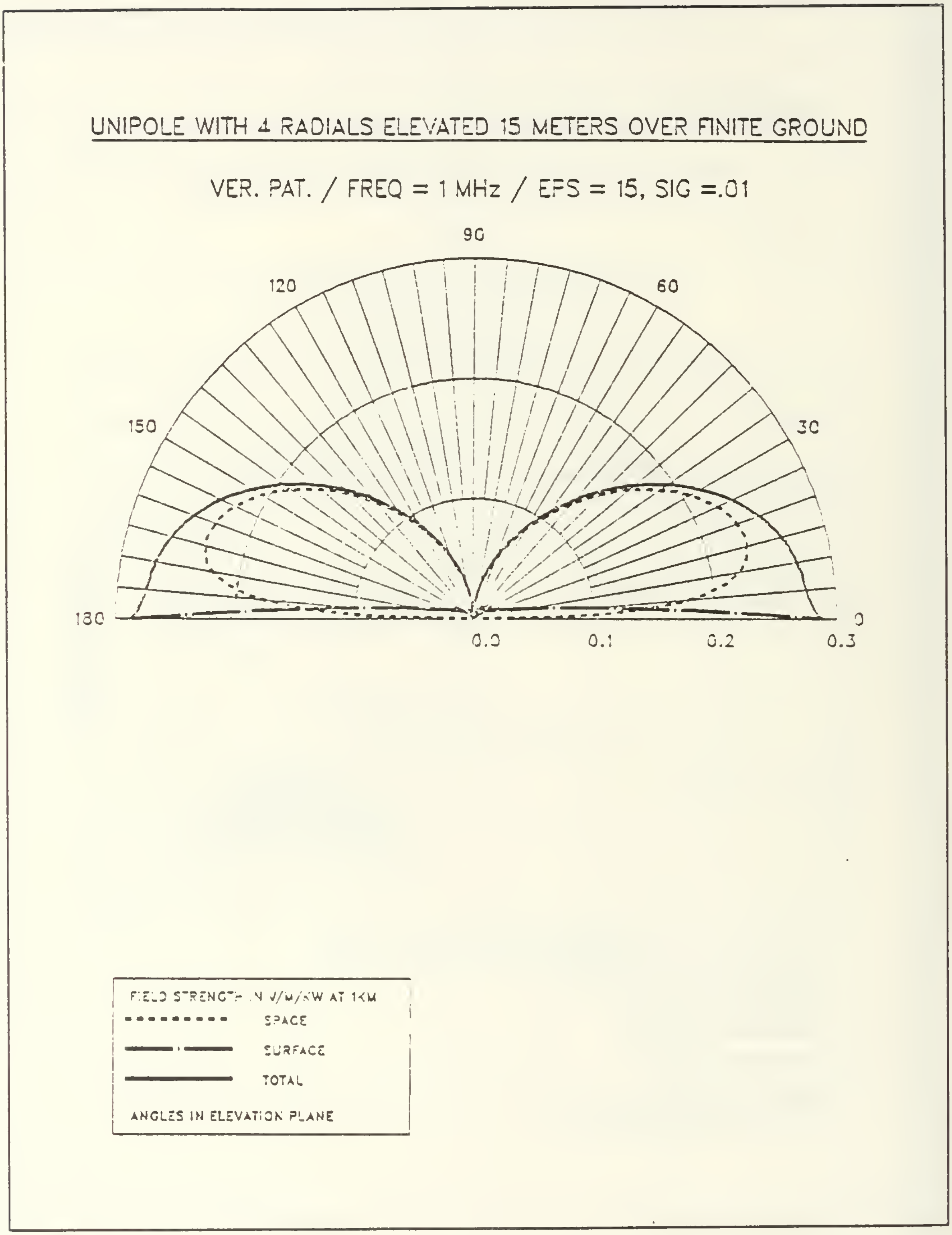

Figure 3.8 Radiation Pattern - Folded Unipole

Elevated 15 Meters Over Finite Ground

C. FOLDED UNIPOLE VARYING THE NUMBER OF ELEVATED RADIALS

Another interesting point of this design is the effect of surface and space wave field strength when varying the number of elevated radial wires. In this case the elevation is not changing and remains at 5 meters and the number of radials changes from 1 to 3. The data sets used to model these antennas are given in Appendix D.2 through D.4. Figures 3.9 through 3.11 illustrate these antennas with different numbers of radials.

As Figure 3.12 shows, the surface and space wave field increases when the number of radials increases up to 2. The increment of field strength for 3 and 4 radials, as Table 3 lists, is small. Radiation patterns for these cases are shown in Figures C.7 through C.9.

TABLE 3

90 DEG. UNIPOLE 5 METER OVER FINITE GROUND EFFECT ON GROUND AND SPACE WAVE FIELD VARYING THE NUMBER OF RADIAL WIRES

# of radial wires	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Impedance R Ohms	Impedance X Ohms
1.0	251.3	207.5	266	178
2.0	272.2	224.8	225	110
3.0	272.8	224.8	219	98
4.0	277.4	228.5	216	96

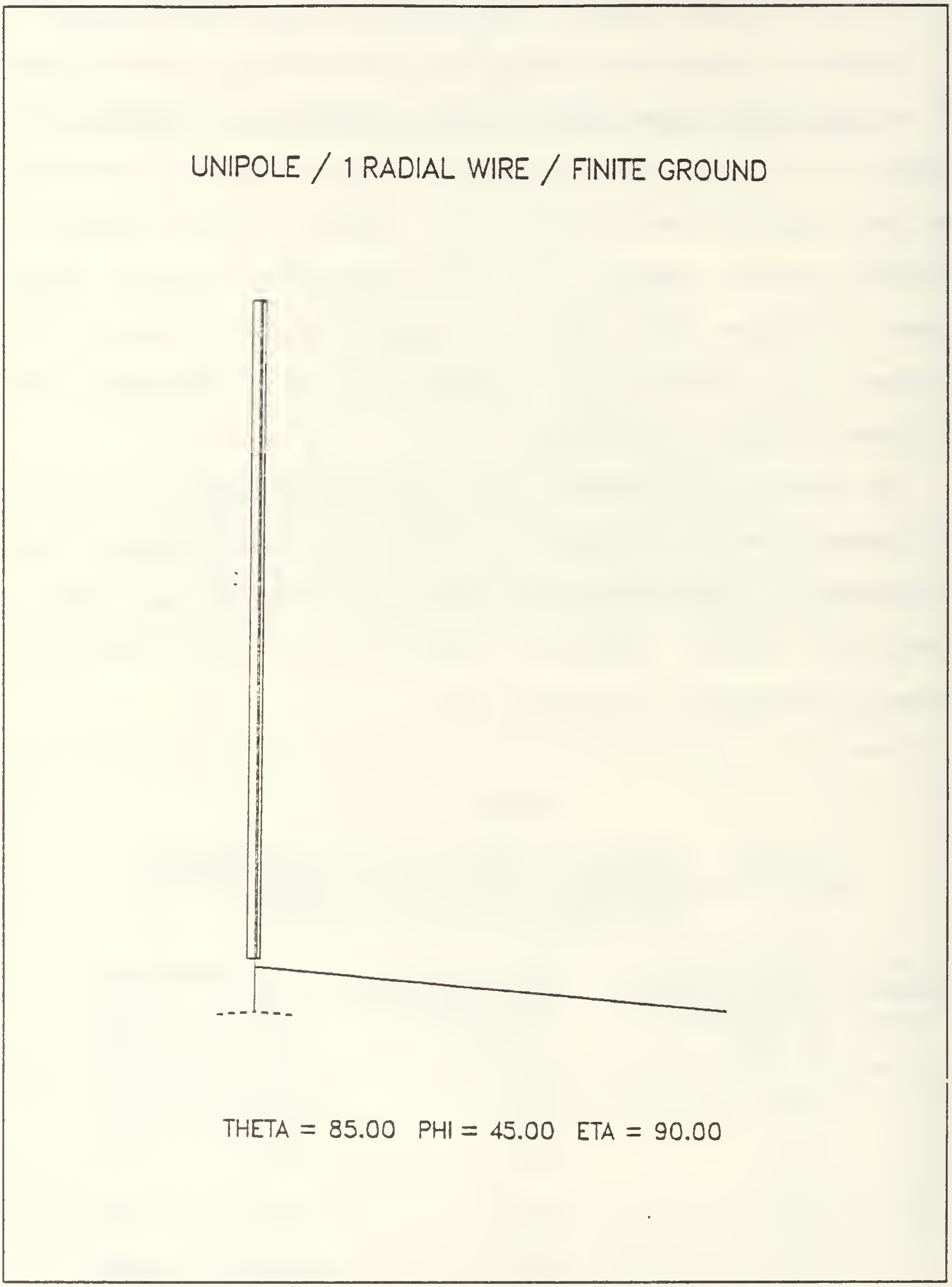

Figure 3.9 Folded Unipole With 1 Radial Wire

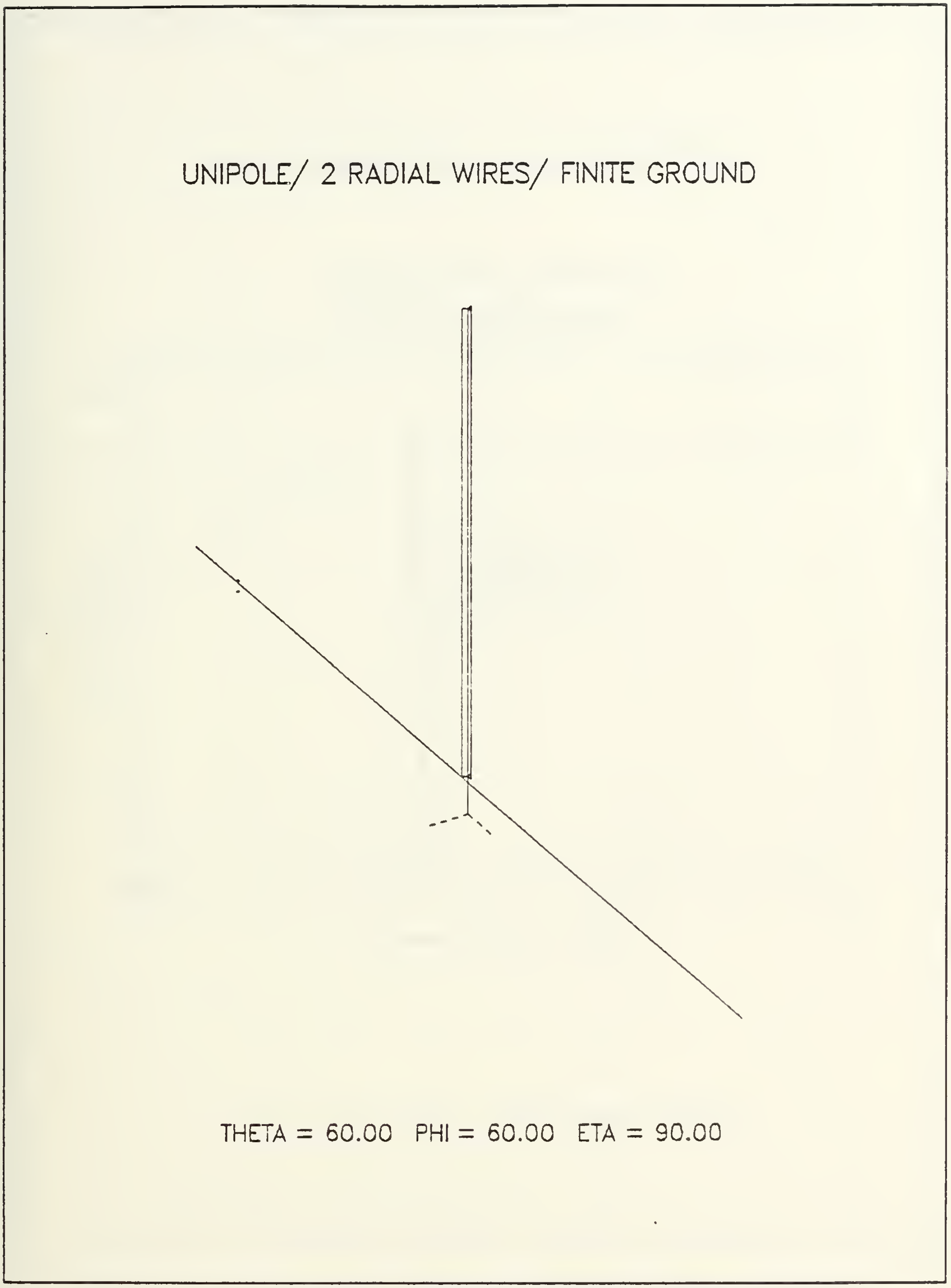

Figure 3.10 Folded Unipole With 2 Radial Wires

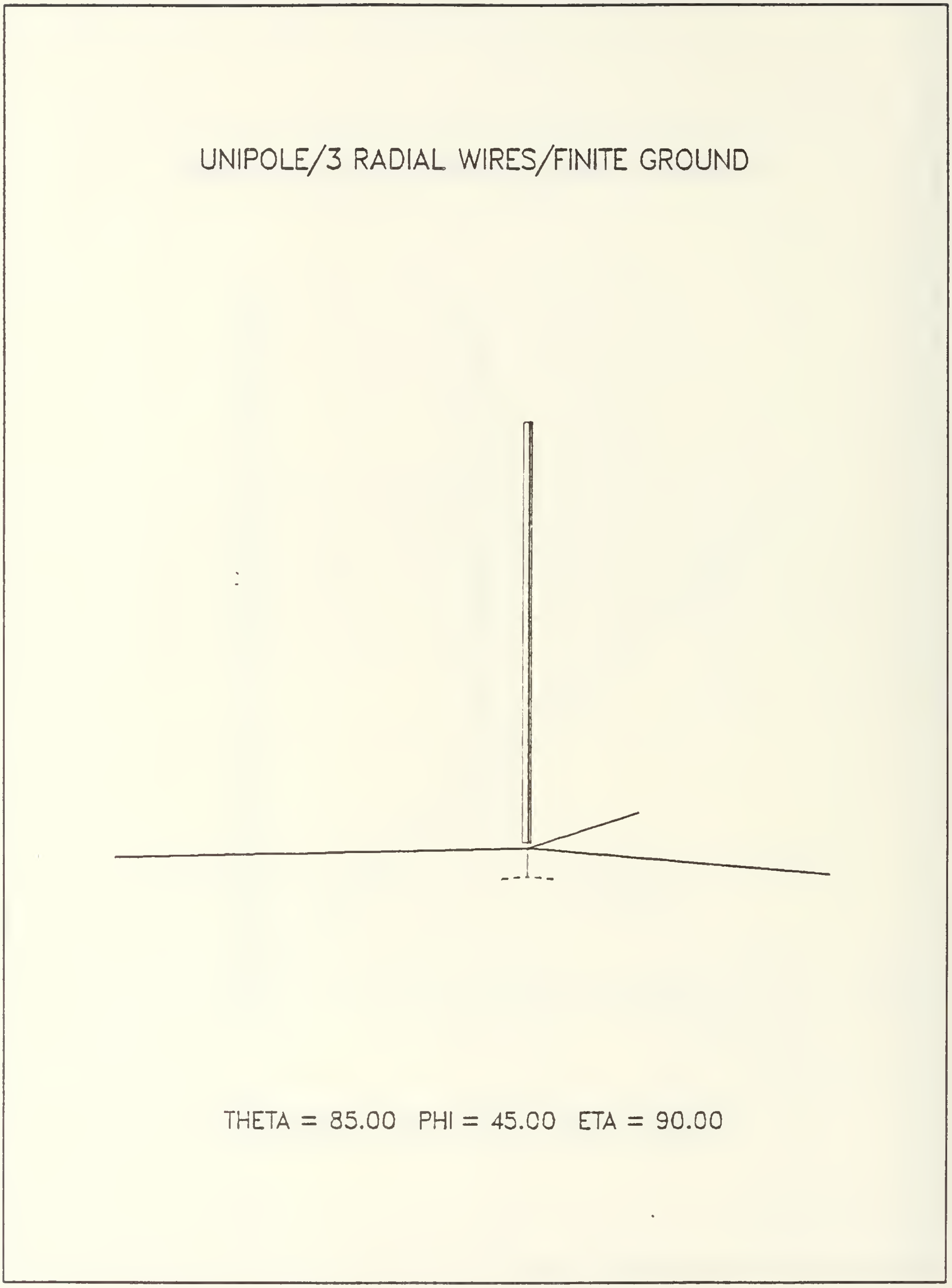

Figure 3.11 Folded Unipole With 3 Radial Wires

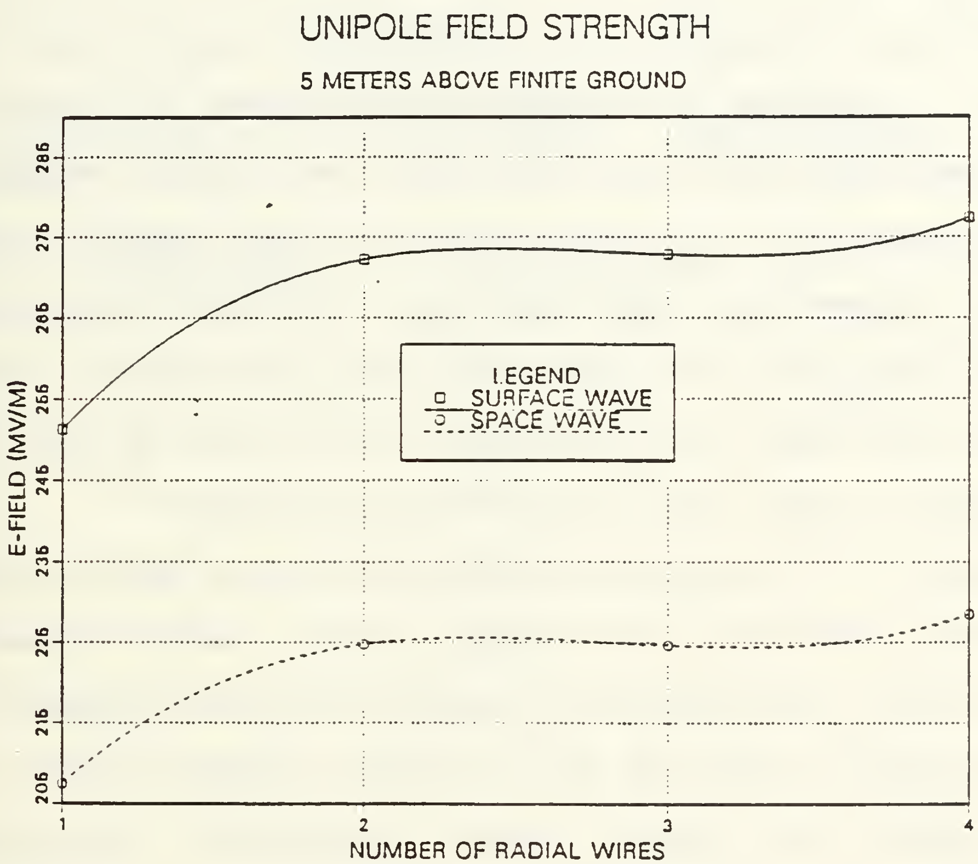

Figure 3.12 Folded Unipole Electric Field Strength When Varying The Number Of Radial Wires

D. 90 DEGREE MONOPOLE WITH 4 RADIAL WIRES

This model shown in Figure 3.13 has 4 radials like the folded unipole to simulate the ground screen and is elevated from 1 to 15 meters over perfect and finite ground (σ=0.01 mhos/M, ε=15).

Appendix D.5 shows a typical data set used to model this antenna. There are two different cases with this model. In the first case the feed point is at the bottom segment of the monopole and in the second case the feed point is at the second segment up. We tried two different feed points because NEC guidelines suggest avoiding feed points close to a point with many wires junctions, as we have in this model (junctions of the radial wires with the tower).

Figure 3.14 illustrates the average power gain decreases for both cases when the elevation of the radials increases. Also we can see that when feeding the bottom segment, the average power gain has only slightly greater values than when feeding the second segment. Apparently the multiple junction feed location is not a problem for this antenna.

The surface and space wave field strength is almost the same in both cases as Figure 3.15 illustrates. Finally the impedance is nearly the same over perfect and finite ground as Figures 3.16 and 3.17 illustrate and decreases as the elevation increases. Tables 4 and 5 list the variation of field strength and input impedance for different feed points over finite ground. Also Tables 6 and 7 lists the variation

of average power gain and input impedance when the antenna is elevated over perfect ground. Figures C.10 through C.19 show the radiation patterns of these antennas for different feed points and elevations

TABLE 4

90 DEG. MONOPOLE WITH FOUR 90 DEG. RADIALS
EXCITATION ON 1ST BASE SEGMENT - FINITE GROUND
EFFECT ON GROUND AND SPACE WAVE FIELD VARYING HEIGHT

Height meters	Ground Wave Field Strength in mV/M/KW	Space Wave Field Strength in mV/M/KW	Impedance R Ohms	Impedance X Ohms
1.0	267.4	221.2	43.7	28.5
3.0	275.1	227.1	40.9	13.9
5.0	279.0	229.9	39.4	9.0
10.0	285.3	233.4	36.8	3.9
15.0	291.2	236.3	34.8	1.4

TABLE 5

90 DEG. MONOPOLE WITH FOUR 90 DEG. RADIALS
EXCITATION ON 2^{ND} BASE SEGMENT - FINITE GROUND
EFFECT ON GROUND AND SPACE WAVE FIELD VARYING HEIGHT

Height meters	Ground Wave Field Strength in mV/M/KW	Space Wave Field Strength in mV/M/KW	Impedance R Ohms	Impedance X Ohms
1.0	263.3	217.8	44.3	28.9
3.0	274.1	226.3	41.2	14.0
5.0	279.6	230.4	39.6	9.1
10.0	285.9	234.0	37.0	3.9
15.0	288.9	234.4	35.0	1.4

TABLE 6

90 DEG. MONOPOLE WITH FOUR 90 DEG. RADIALS
EXCITATION ON 1^{ST} BASE SEGMENT - PERFECT GROUND
EFFECT ON AVERAGE POWER GAIN VARYING THE HEIGHT

Height meters	Average Power Gain	Resistance ohms	Reactance ohms
1.0	1.970	39.10	16.83
3.0	1.940	38.98	12.63
5.0	1.937	38.43	9.98
10.0	1.934	36.88	5.65
15.0	1.933	35.33	2.96

TABLE 7

90 DEG. MONOPOLE WITH FOUR 90 DEG. RADIALS
EXCITATION ON 2^{ND} BASE SEGMENT - PERFECT GROUND
EFFECT ON AVERAGE POWER GAIN VARYING THE HEIGHT

Height meters	Average Power Gain	Resistance ohms	Reactance ohms
1.0	1.941	39.64	17.15
3.0	1.927	39.26	12.80
5.0	1.923	38.70	10.12
10.0	1.919	37.17	5.75
15.0	1.918	35.61	3.00

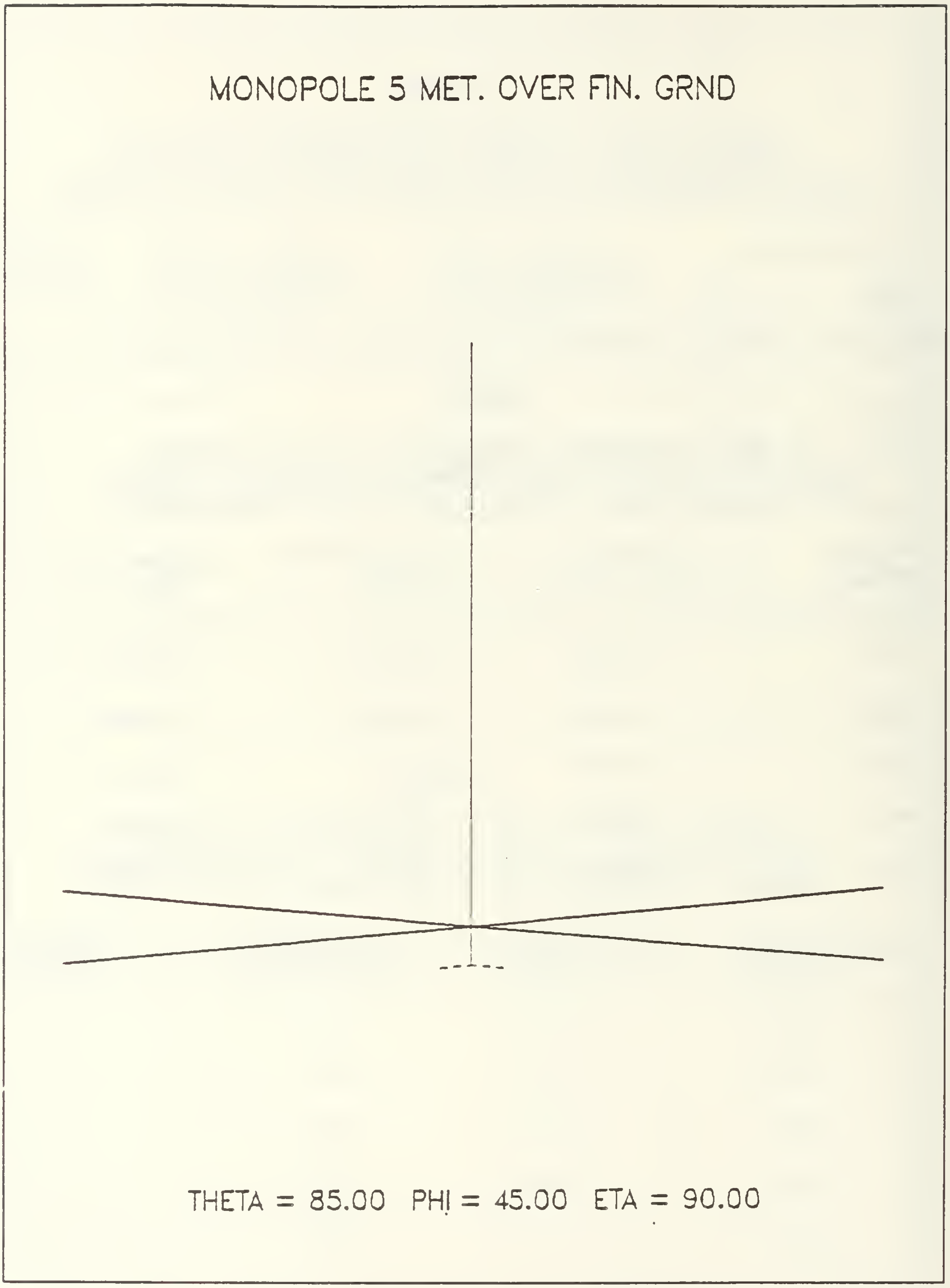

Figure 3.13 Elevated Monopole With 4 Radial Wires

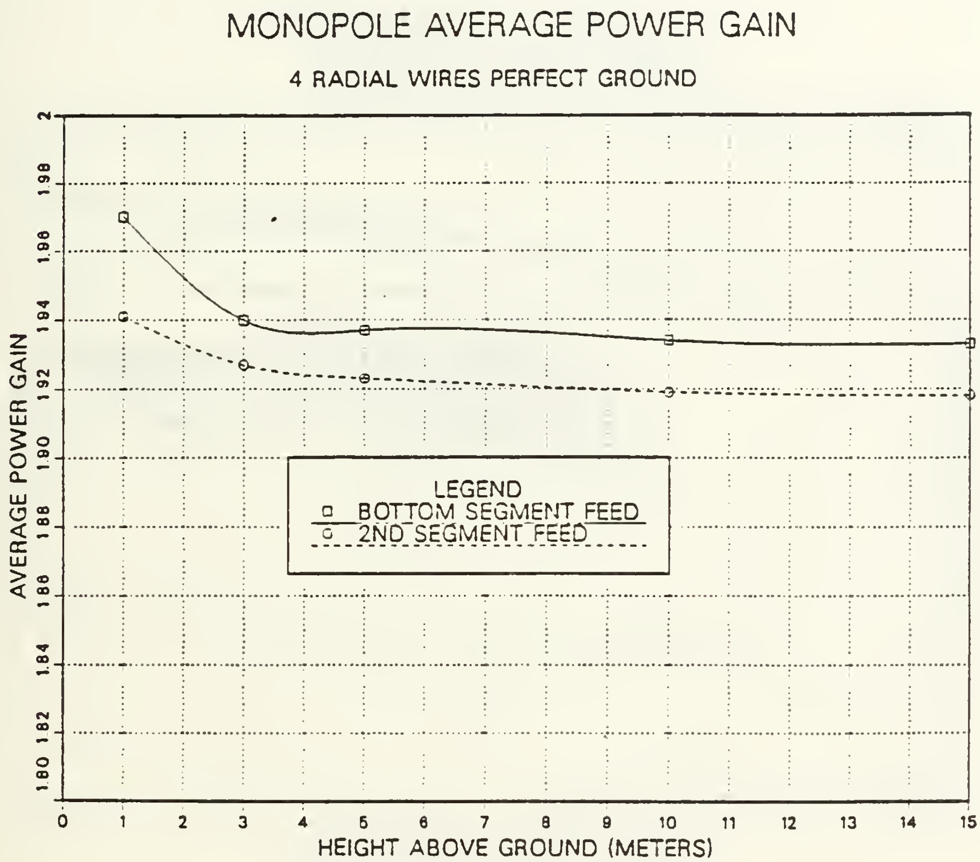

Figure 3.14 Monopole Average Power Gain With 4 Elevated Radial Wires For Different Feed Locations

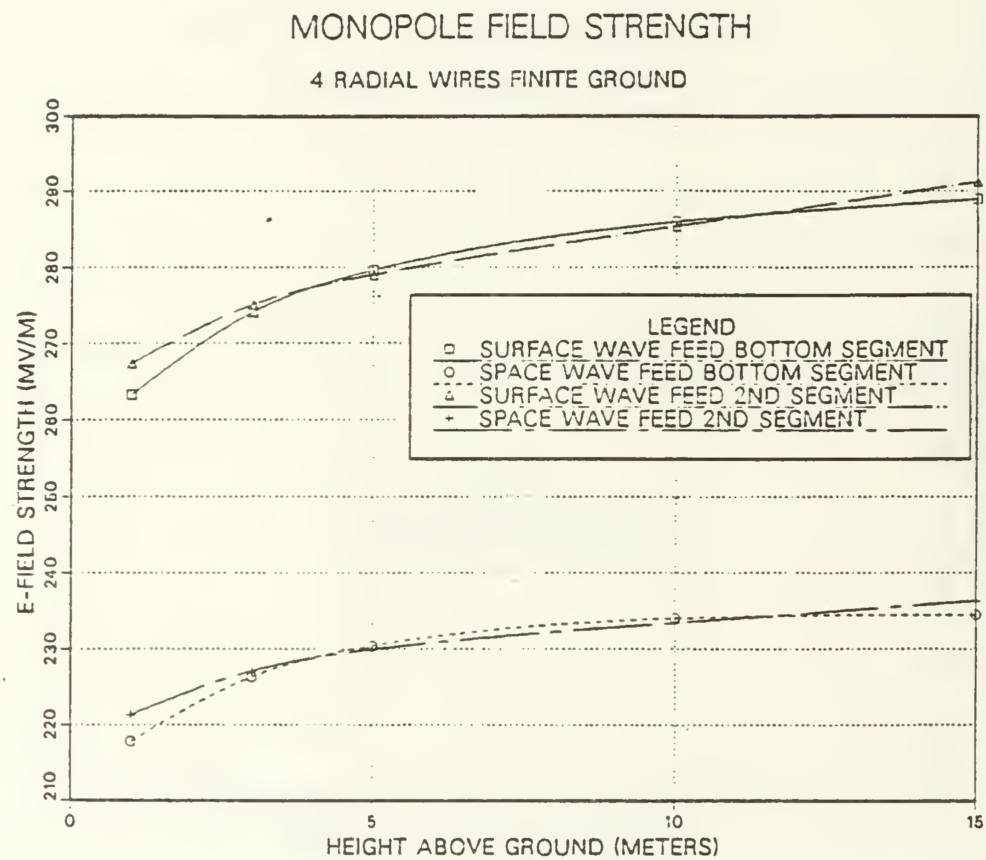

Figure 3.15 Monopole Electric Field Strength With 4 Elevated Radial Wires For Different Feed Locations

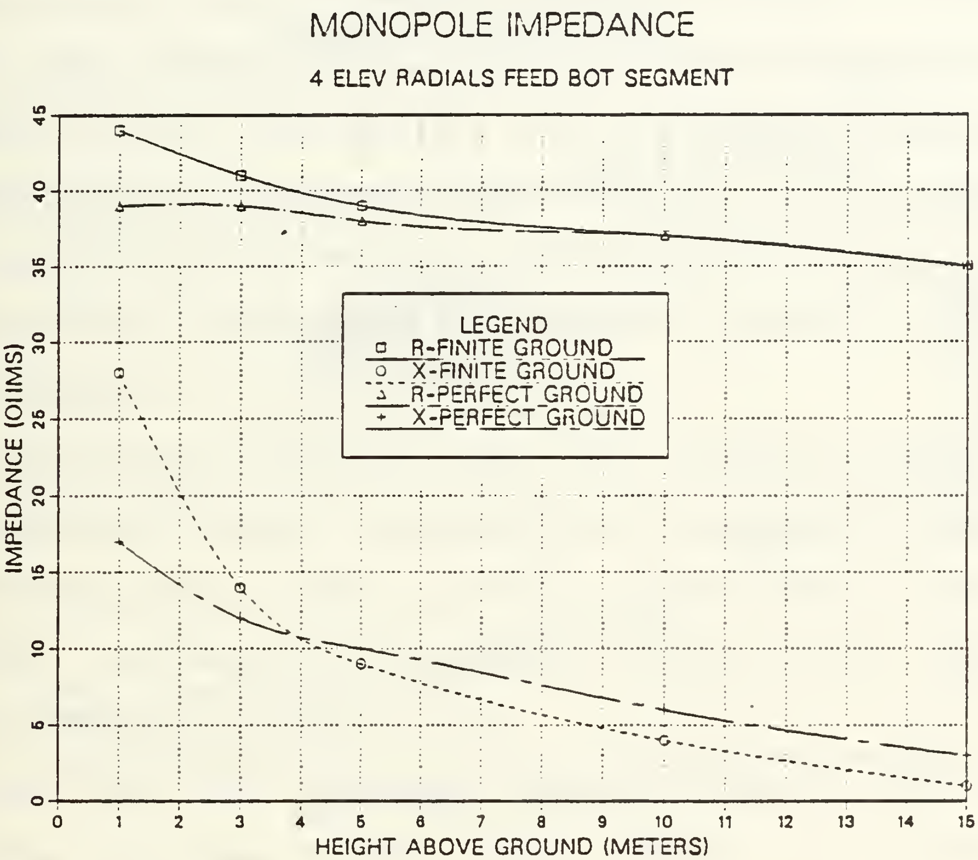

Figure 3.16 Monopole Impedance When Feeding Bottom Segment

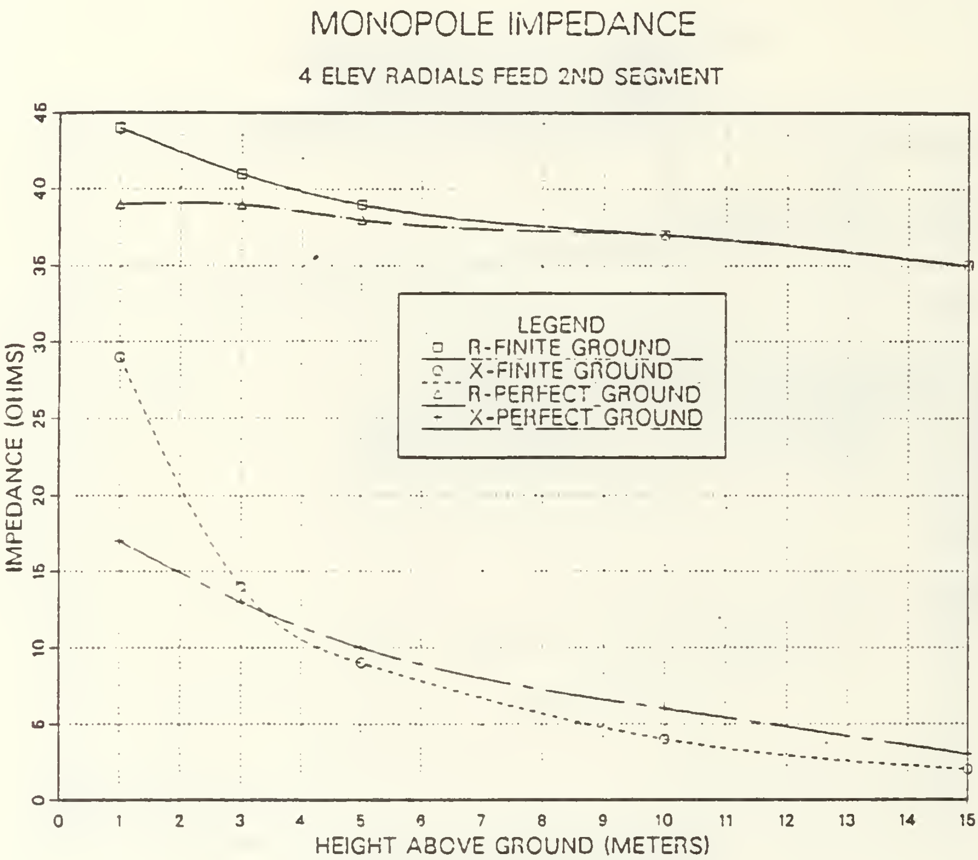

Figure 3.17 Monopole Impedance When Feeding Second Segment

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis has investigated the input impedance, average power gain and electric field strength of a folded unipole and a monopole with 4 radial wires elevated from 1 through 15 meters over perfect and finite ground. This type of antenna with 4 elevated radial wires can use guy wires to hold up the elevated radials, are cheaper and have the same performance as the standard AM broadcast antenna (120 buried radial wires).

The results indicate that the average power gain decreases by 3% when the elevation increases because the space wave power of these antennas drops slightly when the elevation increases. The monopole average power gain is better than the unipole's by 2%.

Also for the elevated folded unipole, the input impedance decreases by 33% and the electric field increases by 6% when the elevation increases. Comparing the radiation patterns of these elevated-radial antennas with a standard AM broadcast antenna radiation pattern (a quarter-wave monopole with 120 buried radial wires), we see they are very close to the pattern for the standard AM broadcast antenna.

Reducing the number of elevated radials below 4 (the suggested number by Christman and Radcliff, for monopoles)

[Ref.6] in the case of the unipole antenna, results in a drop in electric field of 1.7% for 3 radials, 1.9% for 2 radials and 9.5% for 1 radial. This suggests using 3 radials for simplicity of construction.

B. RECOMMENDATIONS

There are some aspects of this study, which need further investigation.

* Determination of the elevated-radial unipole's response at other frequencies over the AM broadcast band.

* Design of multi-frequency unipoles with elevated radials

* Apply elevated radials to unipoles in arrays.

* Investigate elevated-radial unipoles on top of high buildings for use in large city environments where adequate land space for a radial wire ground screen is not available.

APPENDIX A

INTEGRAL EQUATIONS (IE)

The NEC code uses both an electric field integral equation (EFIE) and a magnetic field integral equation (MFIE) to model the electromagnetic response of general structures [Ref.7]. The EFIE is well suited for thin wire structures of small or vanishing conductor volume while the MIEF, is more attractive for large smooth closed surfaces. For a structure containing both wires and surfaces the EIEF and MIEF are coupled.

1. ELECTRIC FIELD INTEGRAL EQUATION

The EFIE for thin wires used in NEC is given by:

$$-\hat{s}\bar{E}^{i}(\bar{r}) = \frac{-j}{4\pi\omega\varepsilon} \int_{c(\bar{r})} I(s')(\hat{s}\hat{s}'k^{2} - \frac{\partial^{2}}{\partial s\,\partial s'})g(\bar{r},\bar{r}')ds' \qquad \text{(A1)}$$

Where:

$\hat{s}$ = distance along the wire axis r.

s' = unit vector along the wire axis.

$\bar{E}^{i}(\bar{r})$ = incident electric field at r.

ω = $2\pi f$

ε = permittivity.

I(s') = axial current.

k = $\omega\sqrt{\mu\varepsilon}$

μ = permeability.

$\bar{r}$ = source point.

$\bar{r}'$ = observation point.

$g(\bar{r},\bar{r}')$ = $\exp(-jkR)/R$ = free space Green's function.

R = $[\bar{r} - \bar{r}']$

2. MAGNETIC FIELD INTEGRAL EQUATION

The MFIE for closed conducting surfaces other than wires used in NEC is given by:

$$\bar{J}_s(\bar{r}) = 2\hat{n} \times \bar{H}^{inc}(\bar{r}) + \frac{1}{2\pi}\, \hat{n} \times \int_s \bar{J}_s(\bar{r}') \times \nabla' g \, ds' \qquad \bar{r} \in S' \qquad \text{(A2)}$$

Where:

$\bar{J}_s(\bar{r})$ = surface current density.

$\bar{H}^{inc}(\bar{r})$ = incident magnetic field at the observ. point.

$\hat{n}$ = unit normal vector.

APPENDIX B

NEC INPUT CARD SUMMARY

COMMENT CARDS

* CM: description of run
* CE: description of run

STRUCTURE GEOMETRY CARDS

* GA: wire arc
* GE: end geometry data
* GF: use numerical Green's functions
* GM: shift and duplicate structure
* GP: suppress geometry print
* GR: generate cylindrical structure
* GS: scale structure dimensions
* GW: specify wire
* GX: reflect structure
* SP: specify surface patch
* SM: generate multiple surface patches

PROGRAM CONTROL CARDS

I. Alter Matrix

* EK: extended thin-wire kernel flag
* FR: frequency specification
* GN: ground parameter specification
* KH: interaction approximation range
* LD: structure impedance loading

II. <u>Alter Current</u>

* EX: structure excitation card
* NT: two-port network specification
* TL: transmission line specification

III. <u>Performance Selection</u>

* CP: compute maximum coupling
* EN: end of data flag
* GD: additional ground parameter specifications
* NE: near electric field
* NH: near magnetic field
* NX: next structure flag
* PQ: wire charge density print control
* PT: wire-current print control
* RP: radiation pattern
* WG: write numerical Green's function file
* XQ: execute card.

The required cards used in every **NEC** model are: CE, GE, EX, and EN.

APPENDIX C

RADIATION PATTERN PLOTS

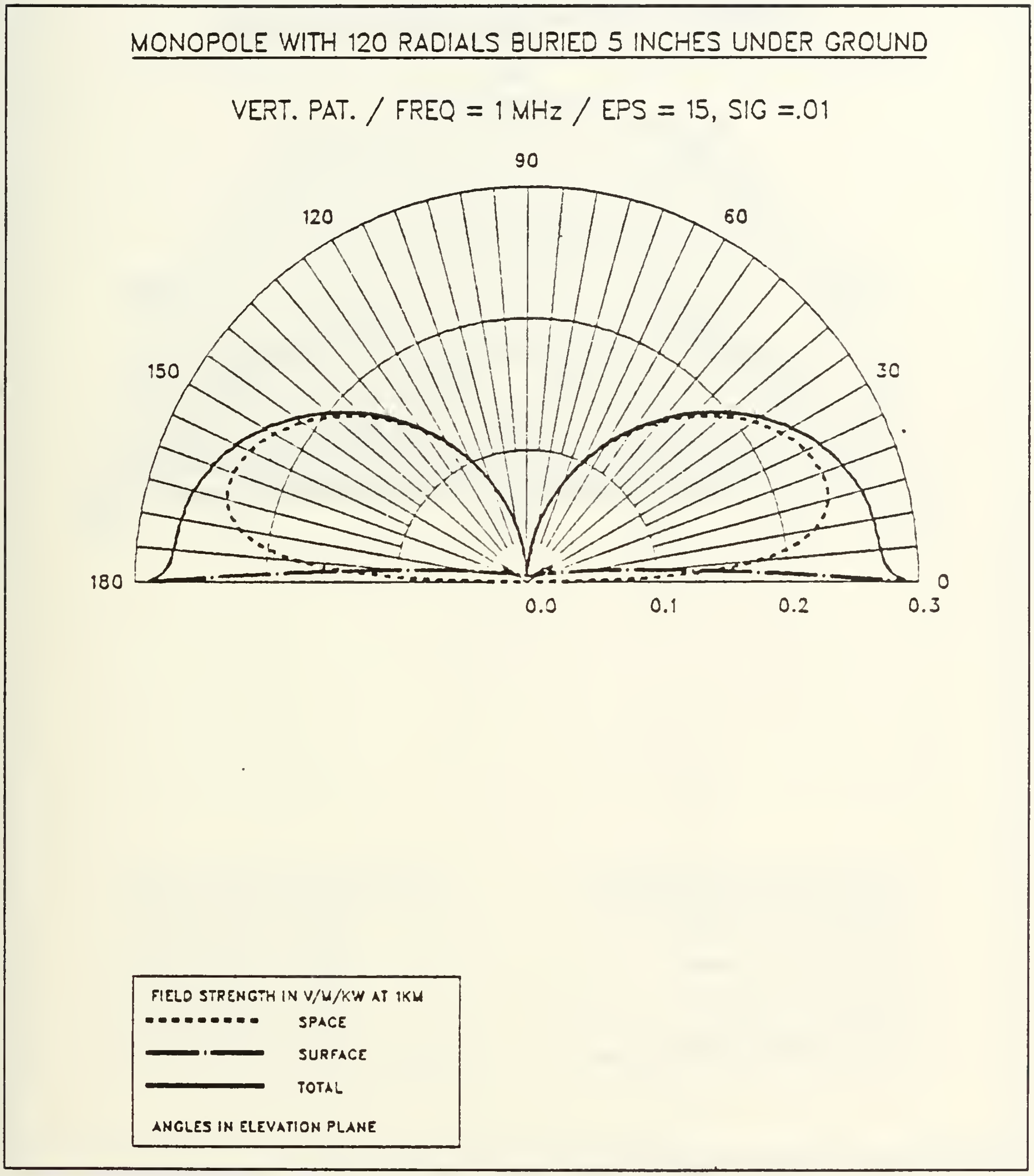

Figure C.1 Radiation Pattern - Monopole With 120 Radial Wires

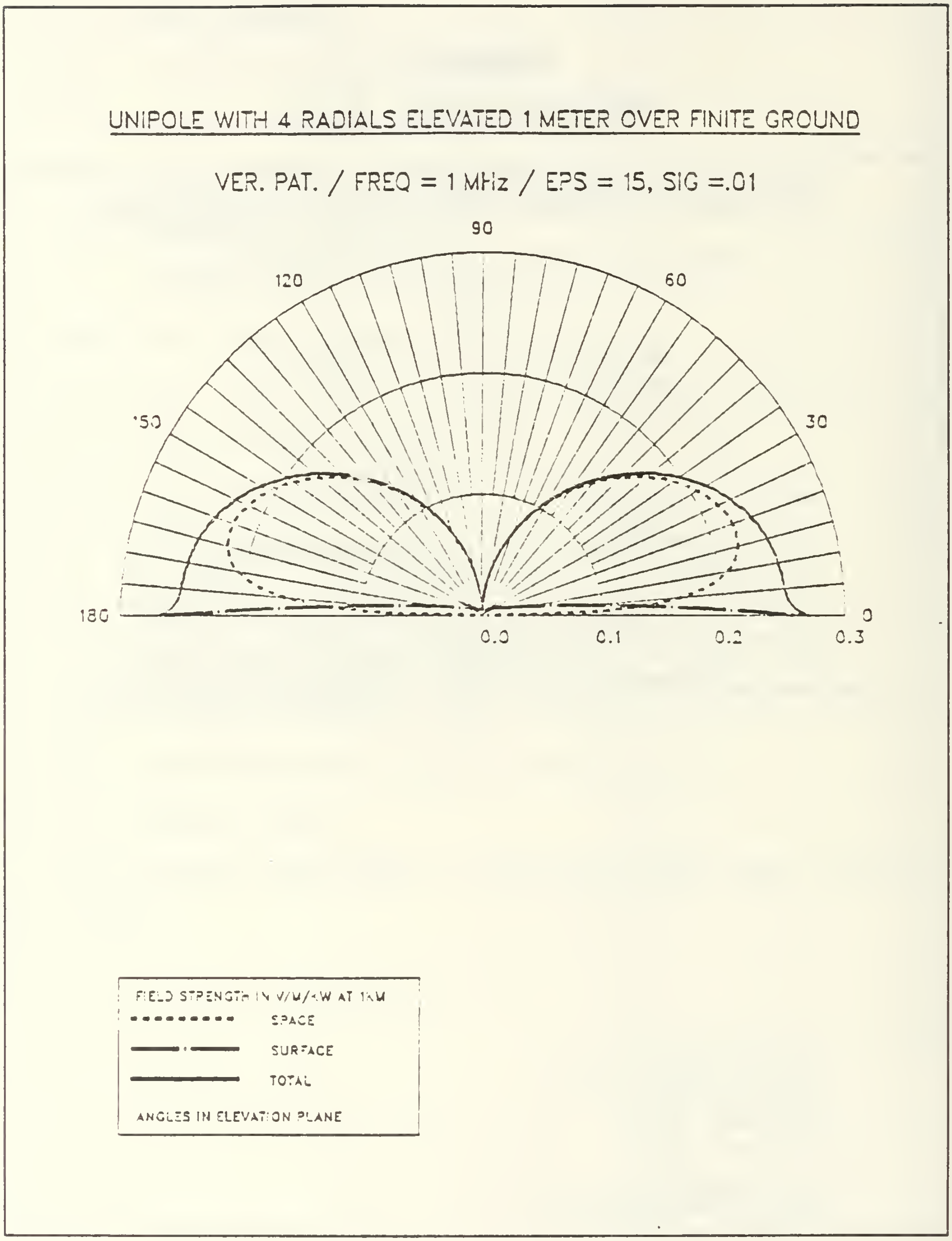

Figure C.2 Radiation Pattern - Folded Unipole

Elevated 1 Meter Over Finite Ground

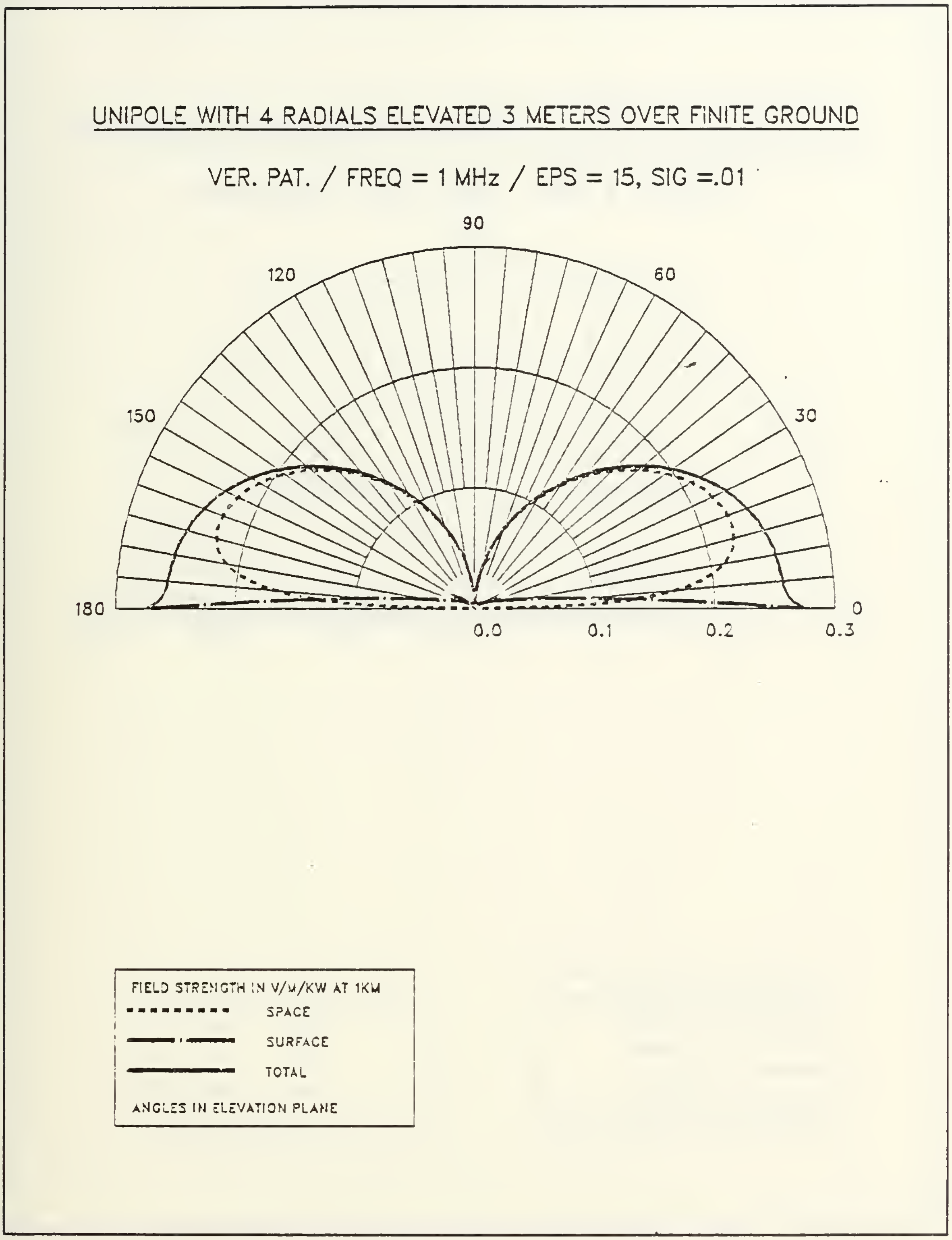

Figure C.3 Radiation Pattern - Folded Unipole

Elevated 3 Meters Over Finite Ground

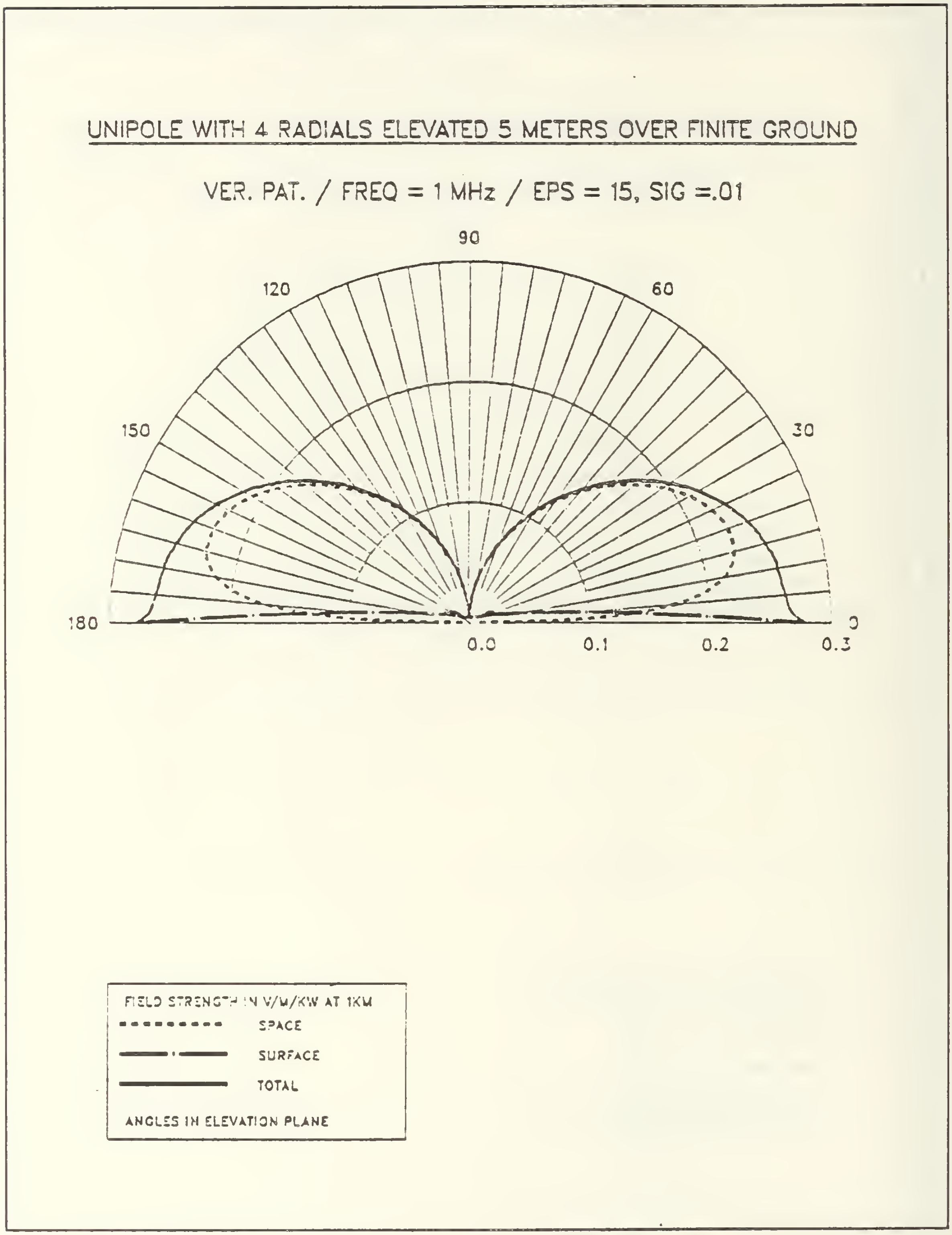

Figure C.4 Radiation Pattern - Folded Unipole Elevated 5 Meters Over Finite Ground

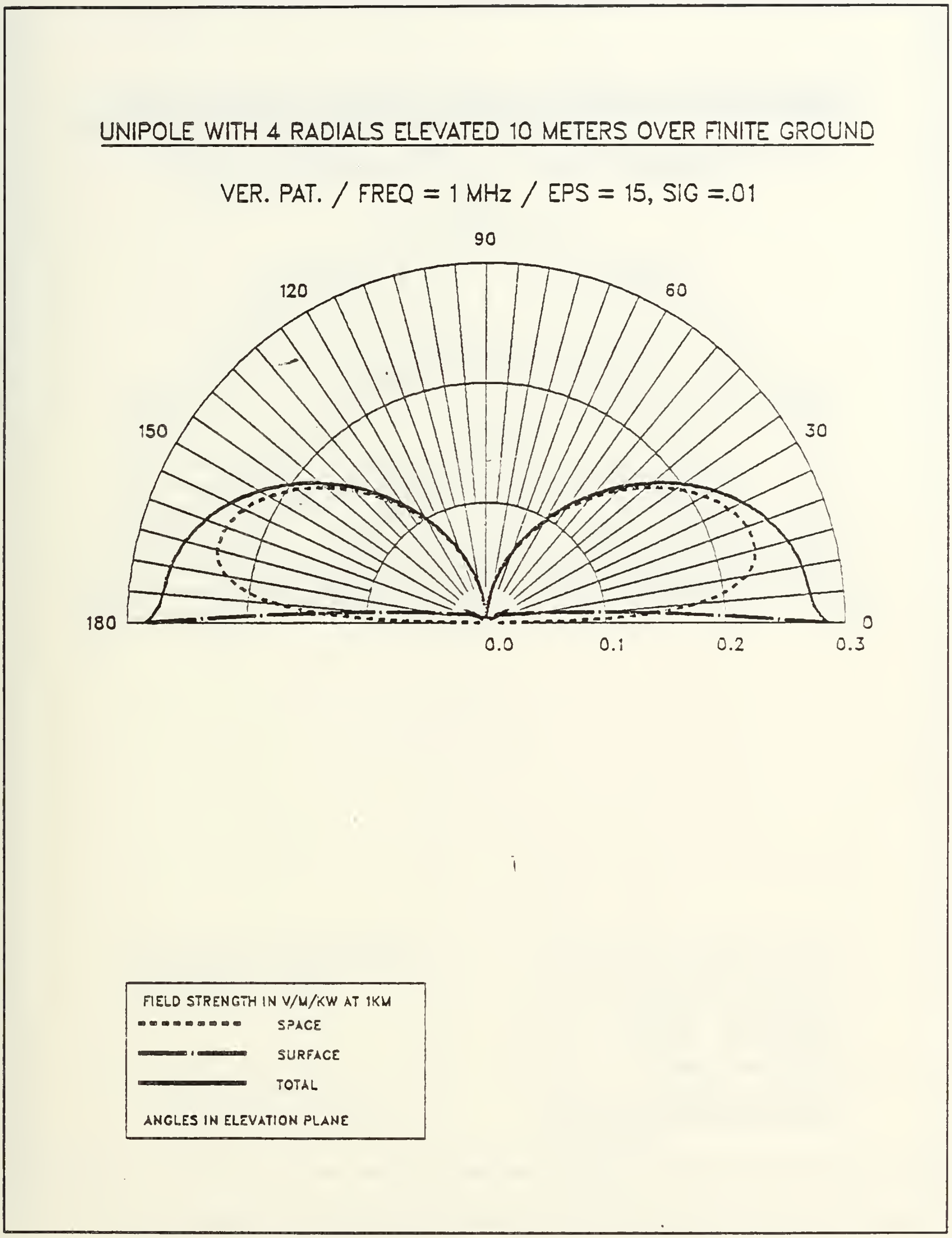

Figure C.5 Radiation Pattern - Folded Unipole Elevated 10 Meters Over Finite Ground

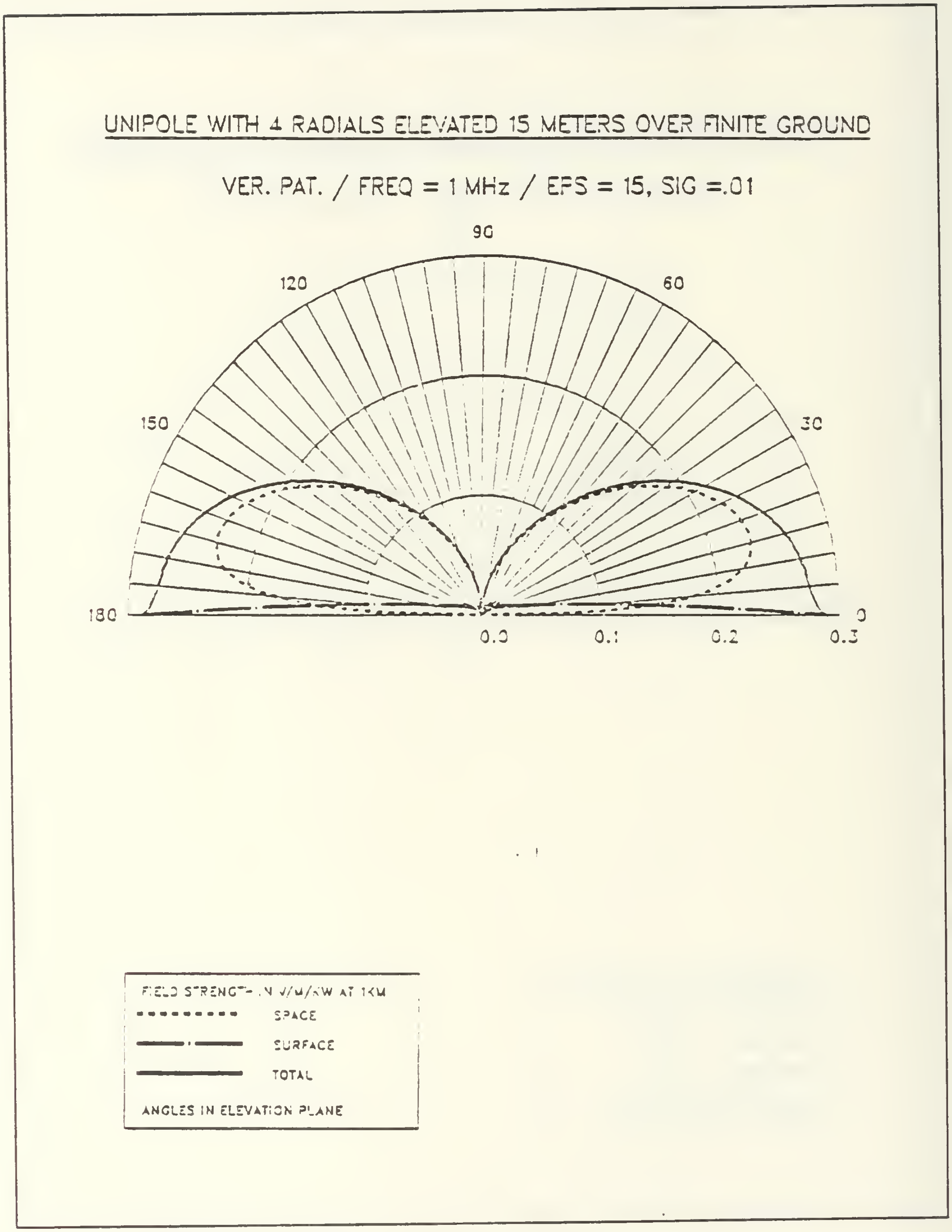

Figure C.6 Radiation Pattern - Folded Unipole

Elevated 15 Meters Over Finite Ground

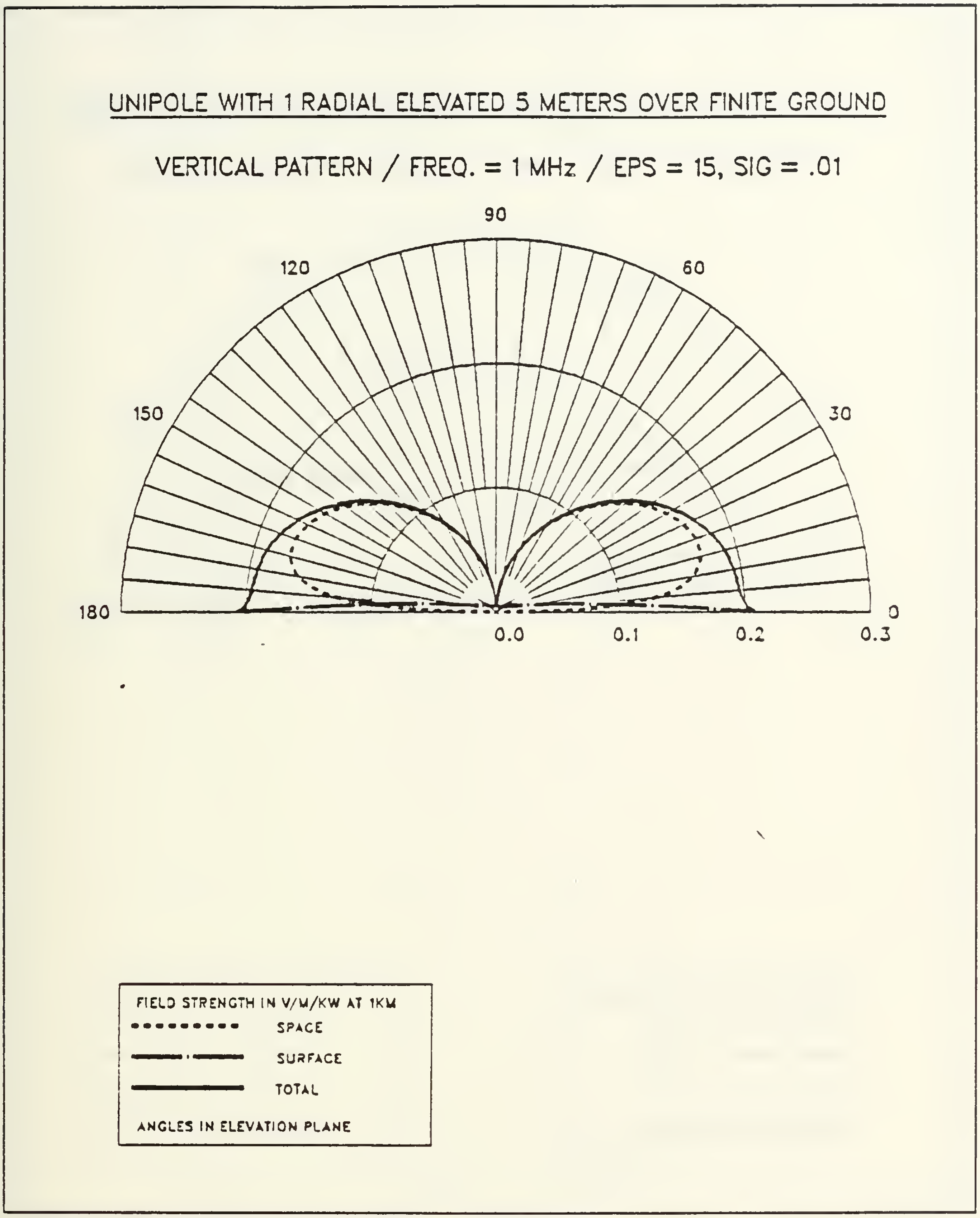

Figure C.7 Radiation Pattern - Folded Unipole

With 1 Radial Elevated 5 Meters

Over Finite Ground

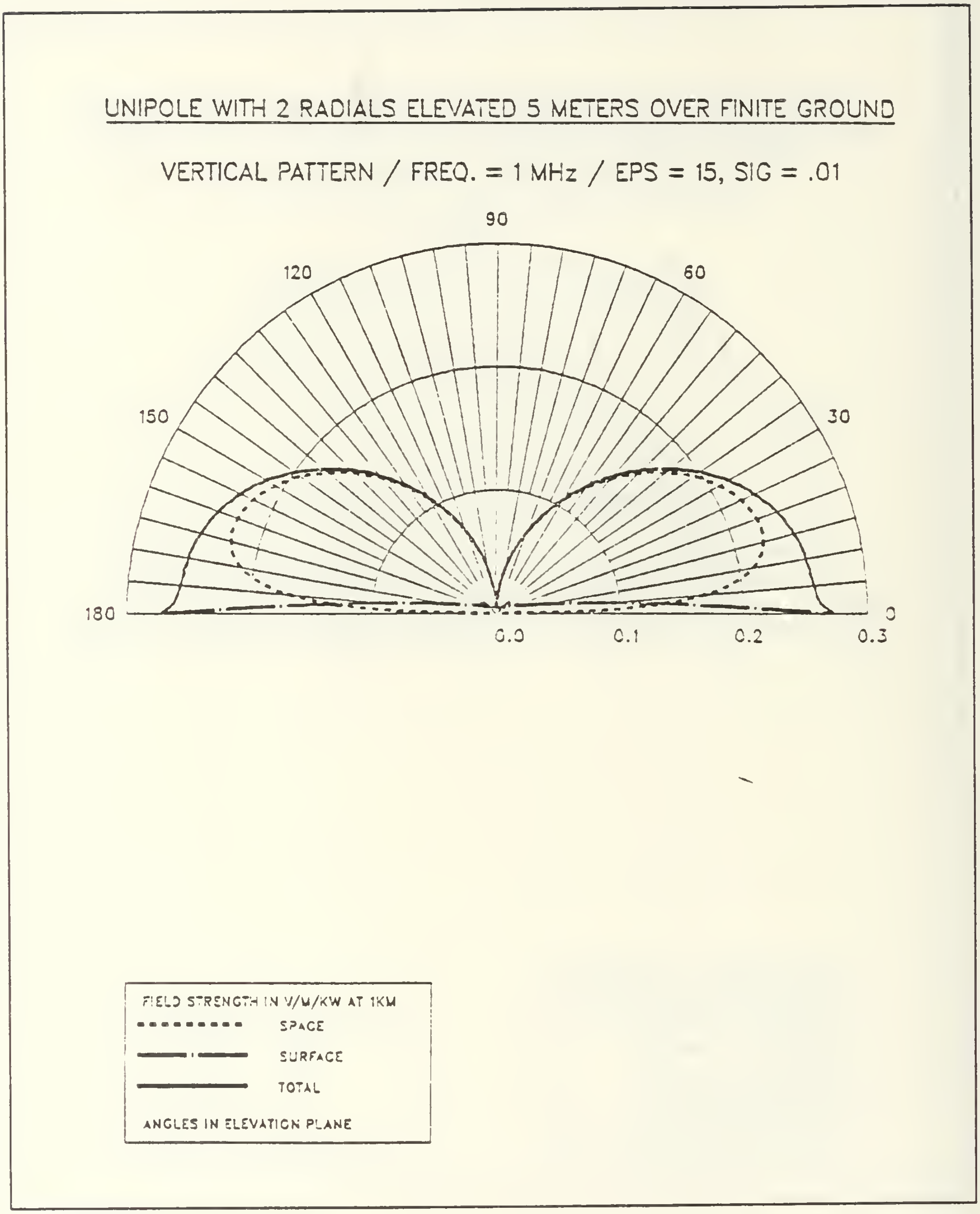

Figure C.8 Radiation Pattern - Folded Unipole With 2 Radials Elevated 5 Meters Over Finite Ground

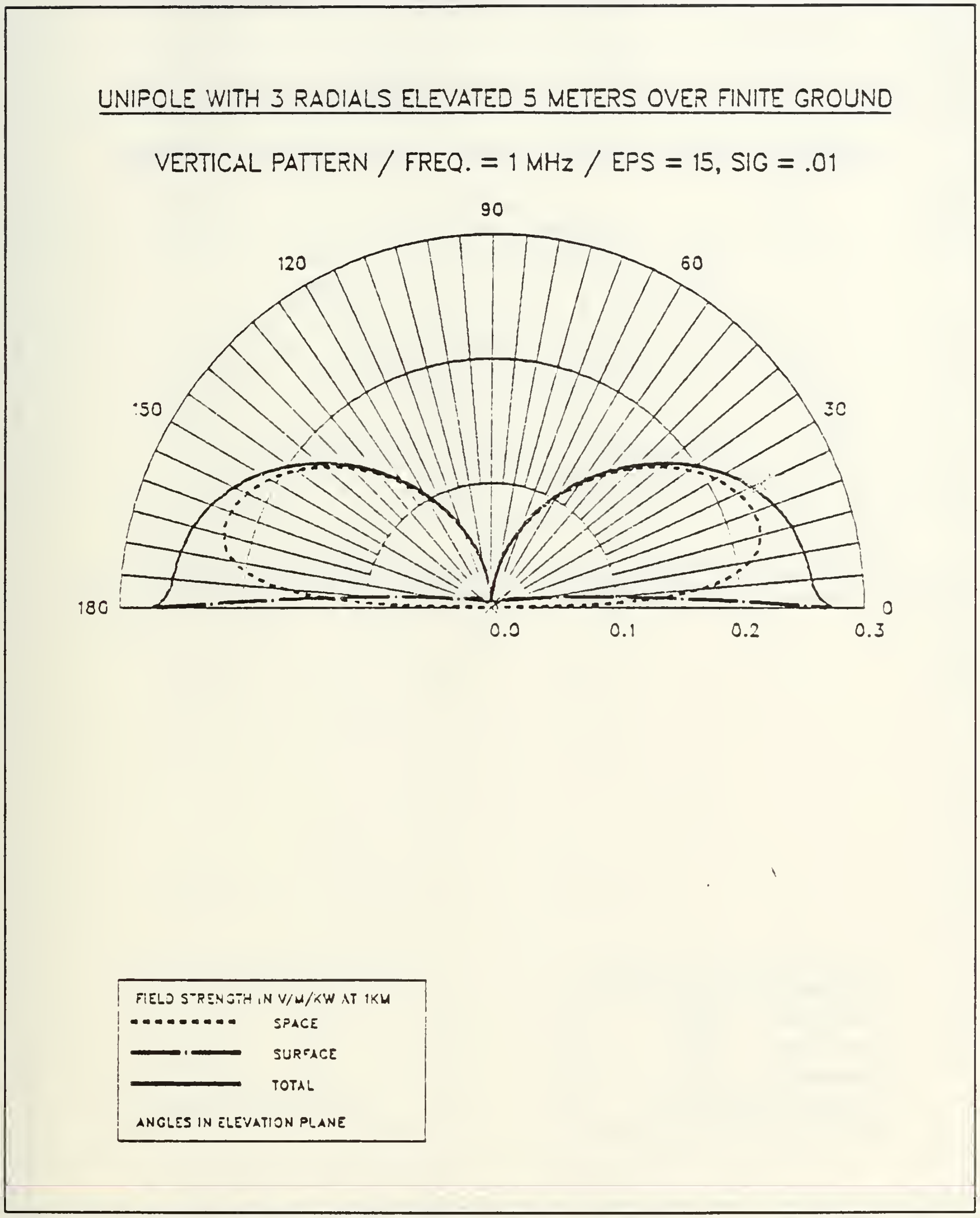

Figure C.9 Radiation Pattern - Folded Unipole

With 3 Radials Elevated 5 Meters

Over Finite Ground

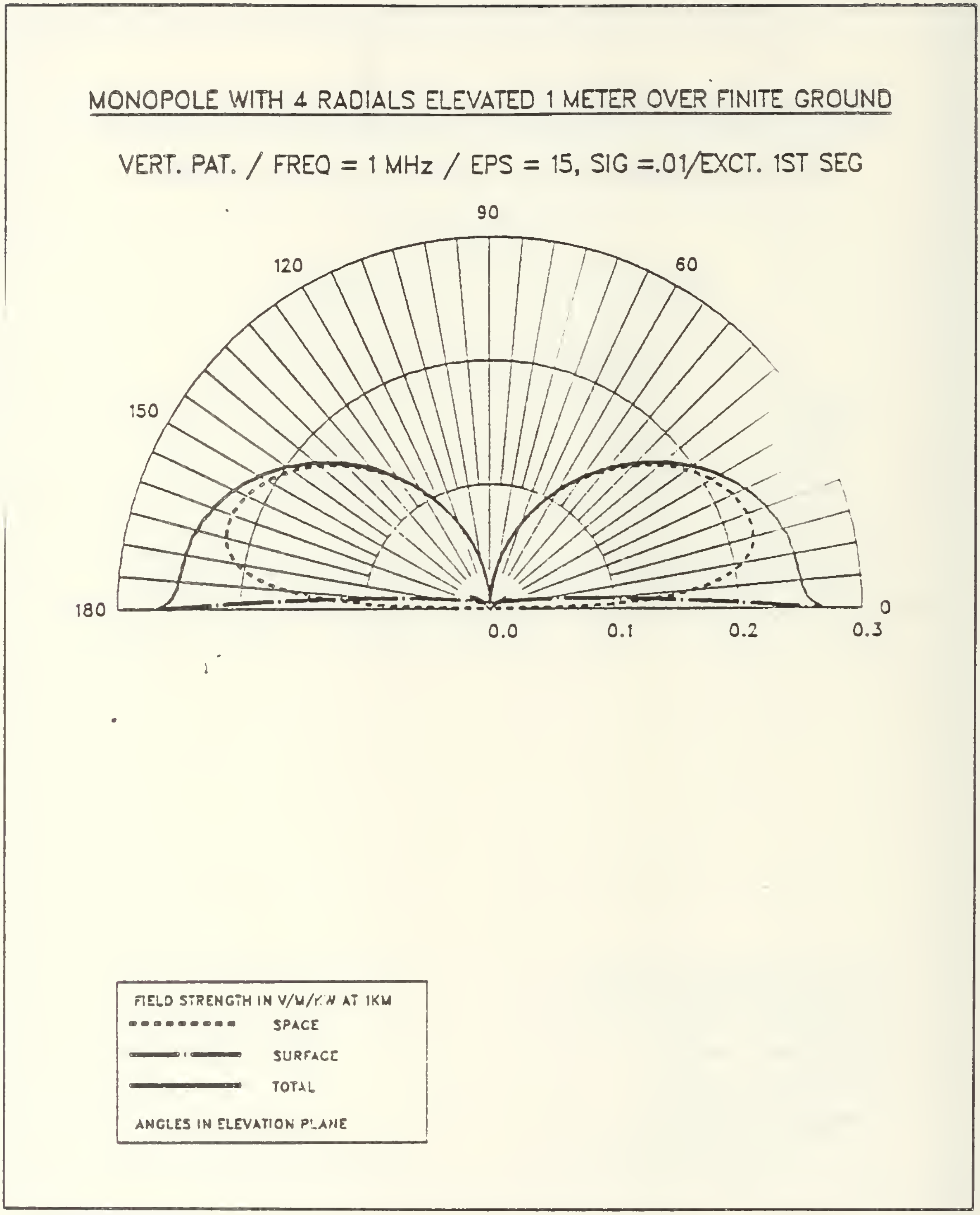

Figure C.10 Radiation Pattern - Monopole With 4 Radials

Elevated 1 Meter Over Finite Ground

Excitation Bottom Segment

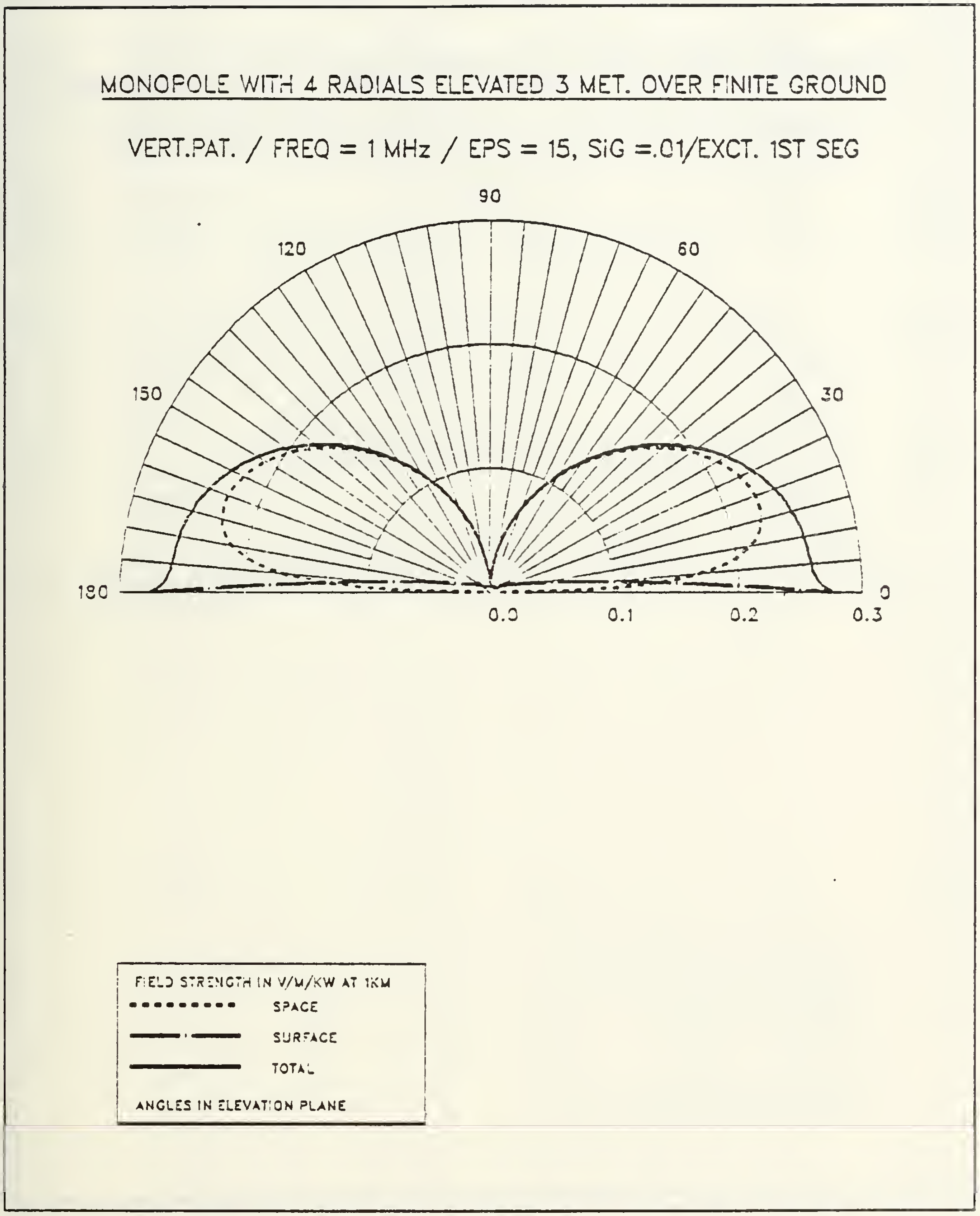

Figure C.11 Radiation Pattern - Monopole With 4 Radials

Elevated 3 Meters Over Finite Ground

Excitation Bottom Segment

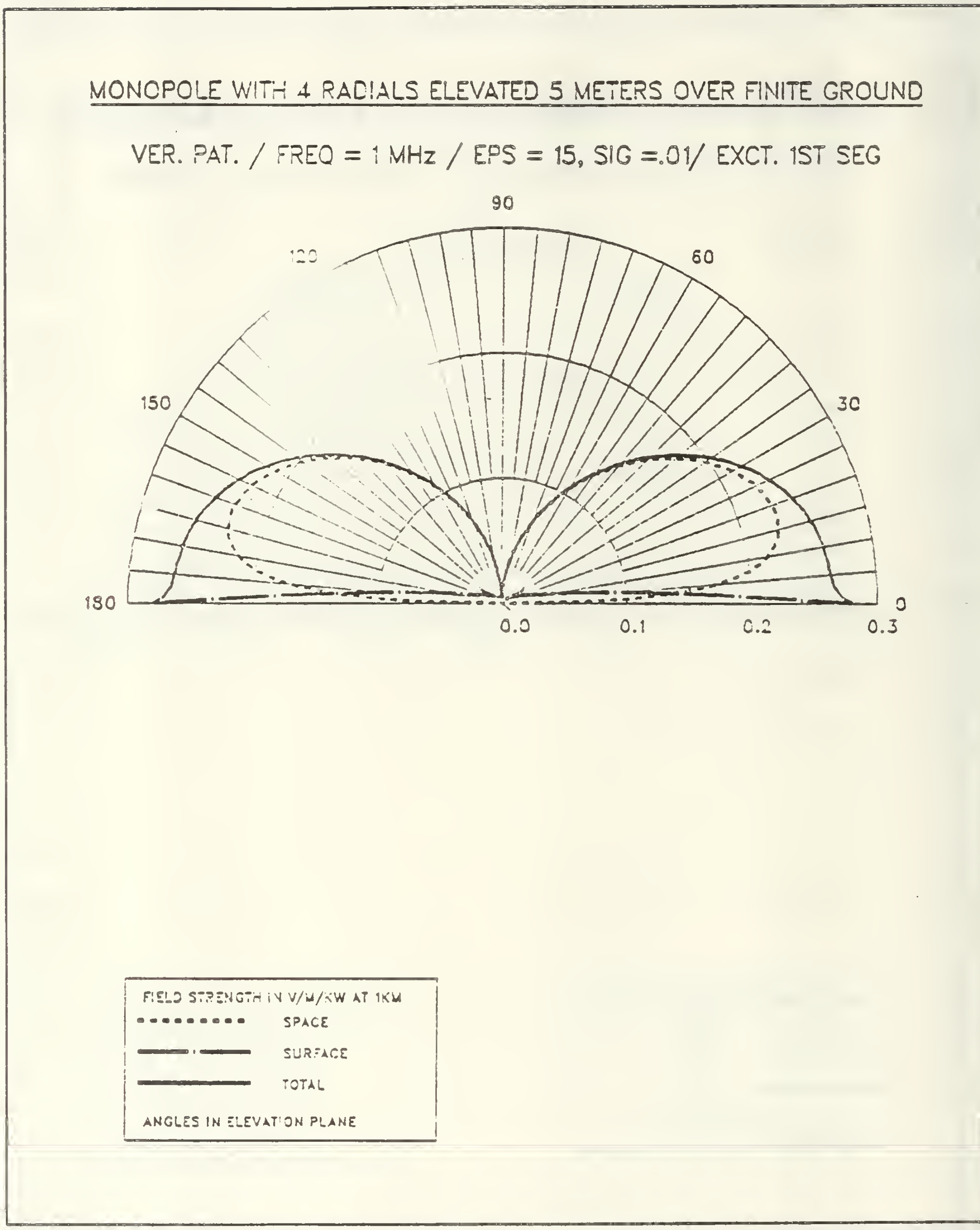

Figure C.12 Radiation Pattern - Monopole With 4 Radials
Elevated 5 Meters Over Finite Ground
Excitation Bottom Segment

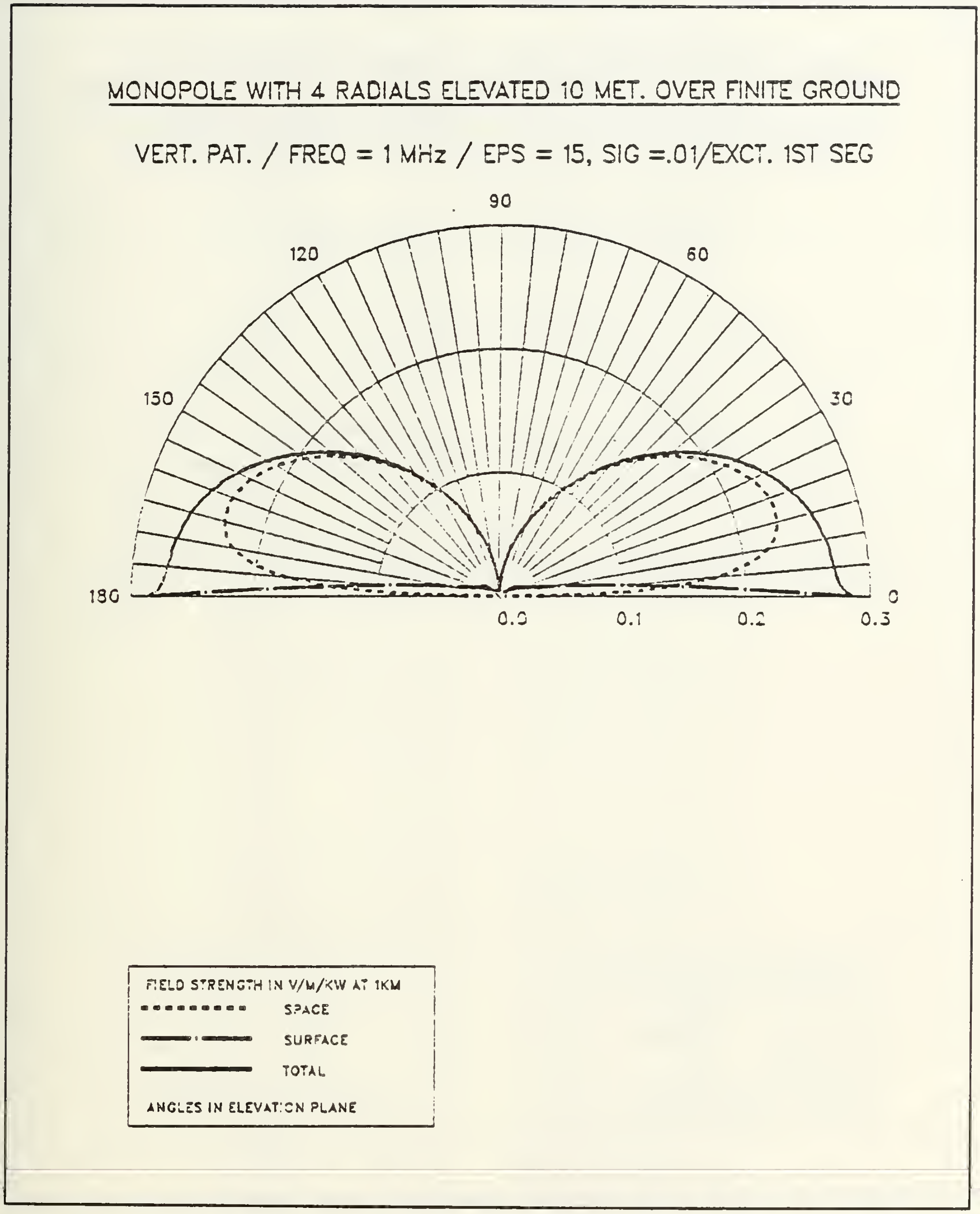

Figure C.13 Radiation Pattern - Monopole With 4 Radials Elevated 10 Meters Over Finite Ground Excitation Bottom Segment

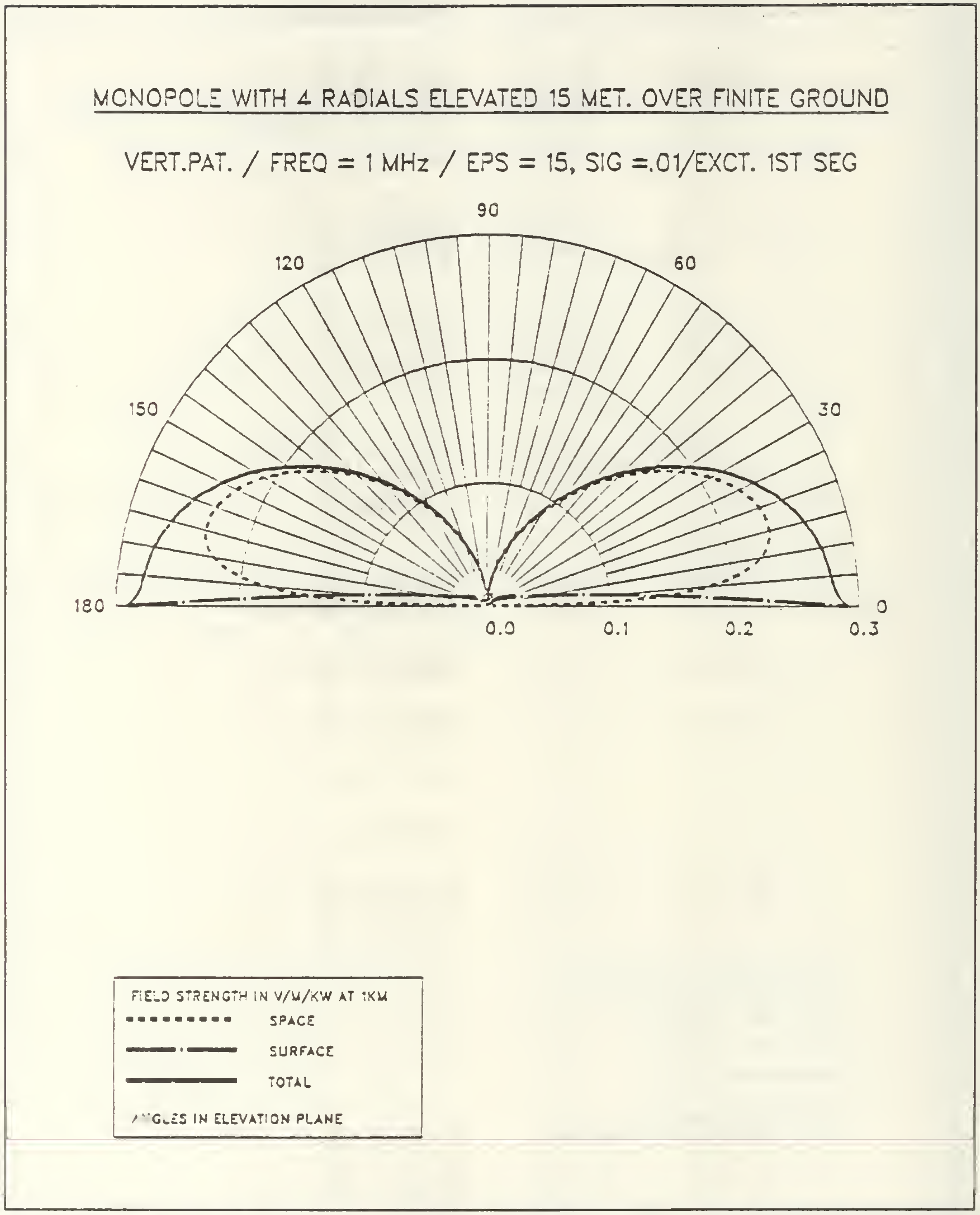

Figure C.14 Radiation Pattern - Monopole With 4 Radials Elevated 15 Meters Over Finite Ground Excitation Bottom Segment

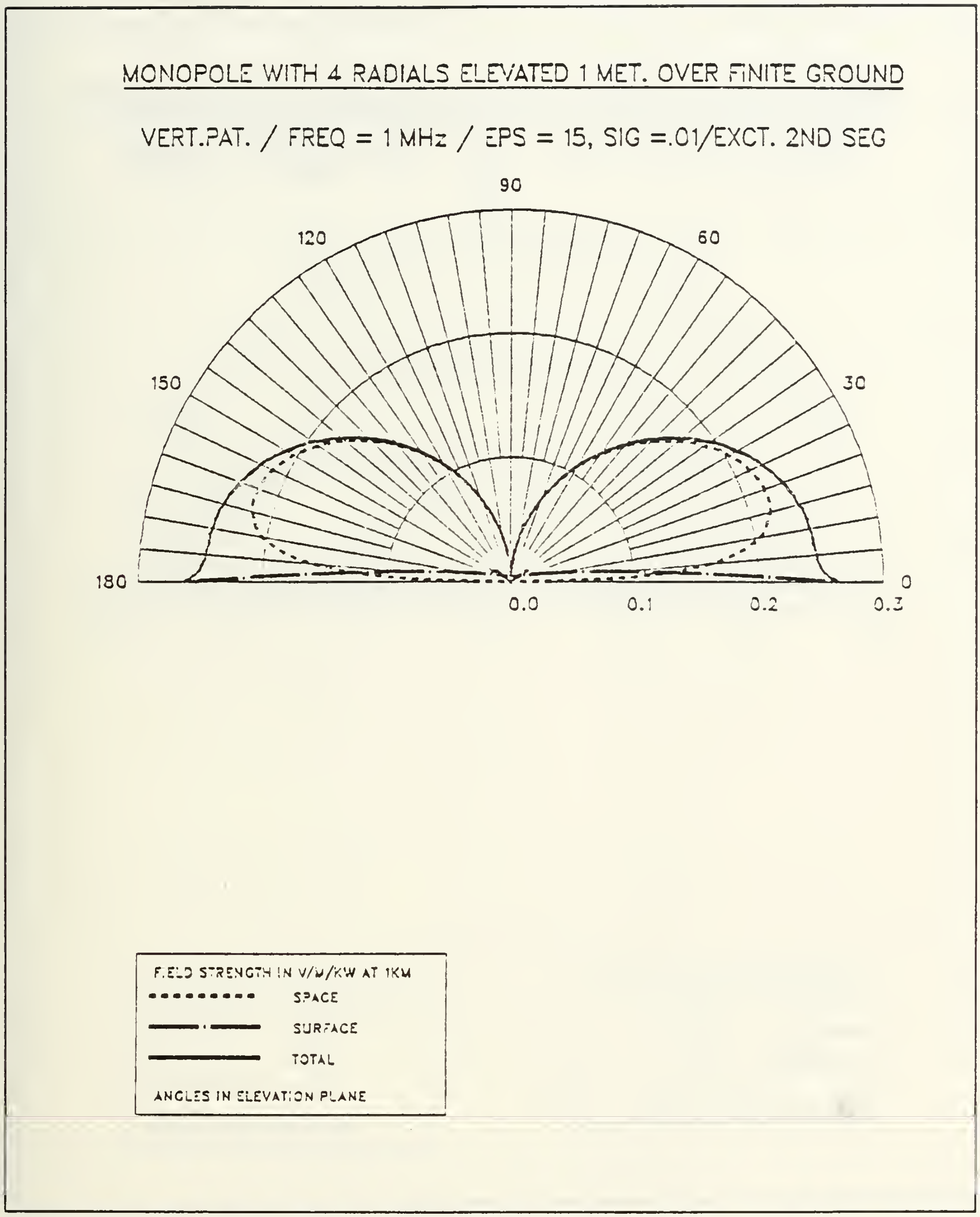

Figure C.15 Radiation Pattern - Monopole With 4 Radials Elevated 1 Meter Over Finite Ground Excitation Second Segment

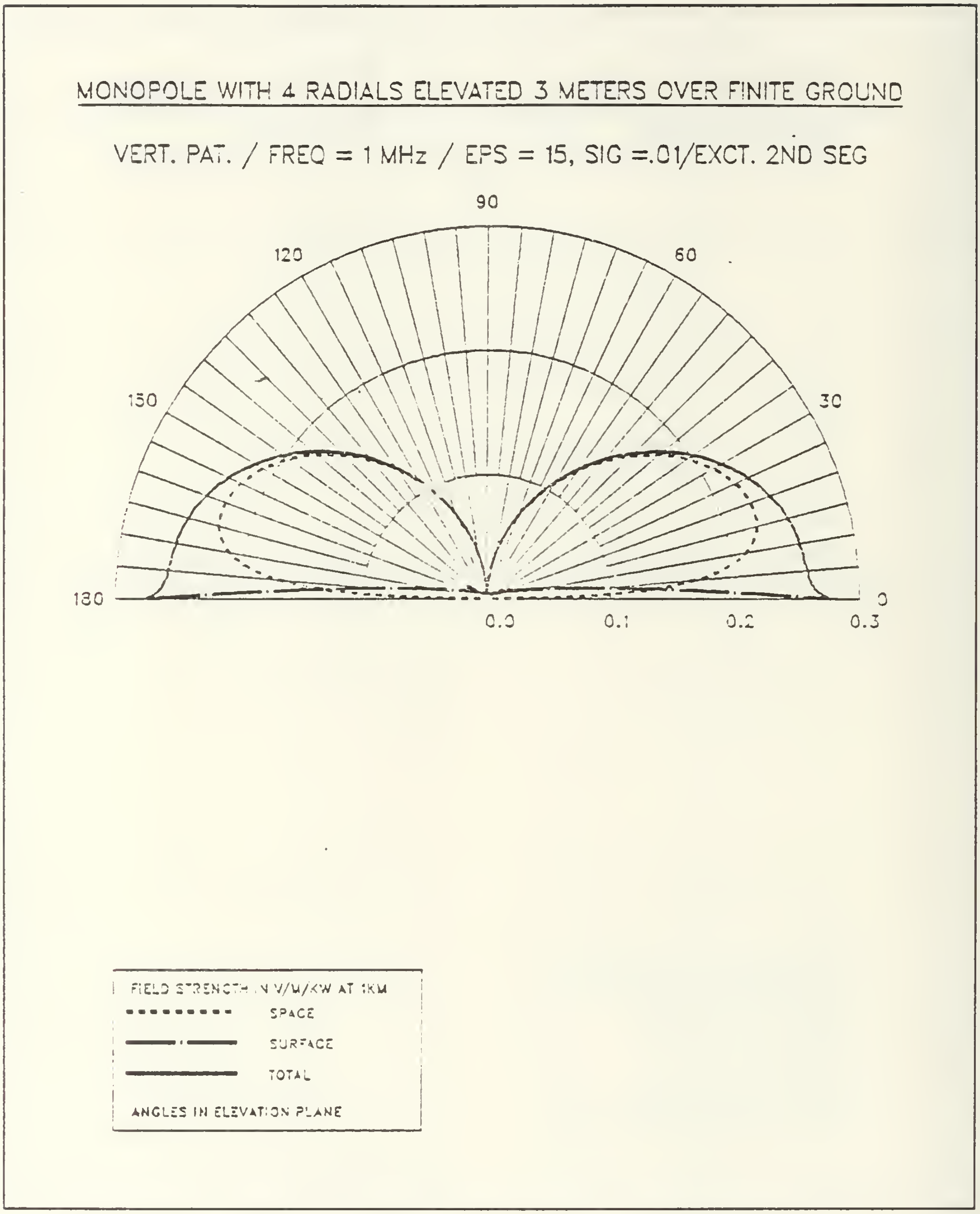

Figure C.16 Radiation Pattern - Monopole With 4 Radials Elevated 3 Meters Over Finite Ground Excitation Second Segment

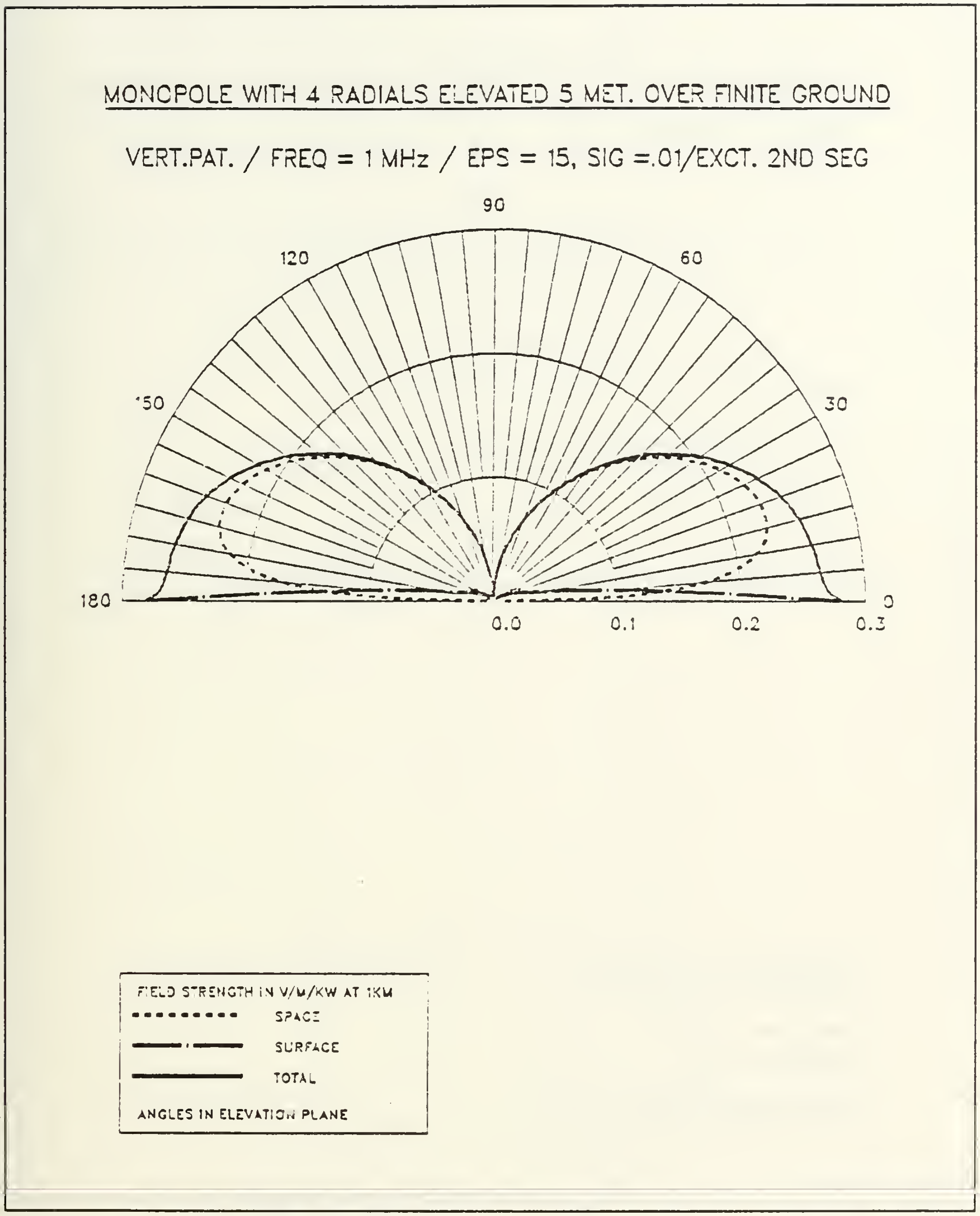

Figure C.17 Radiation Pattern - Monopole With 4 Radials Elevated 5 Meters Over Finite Ground Excitation Second Segment

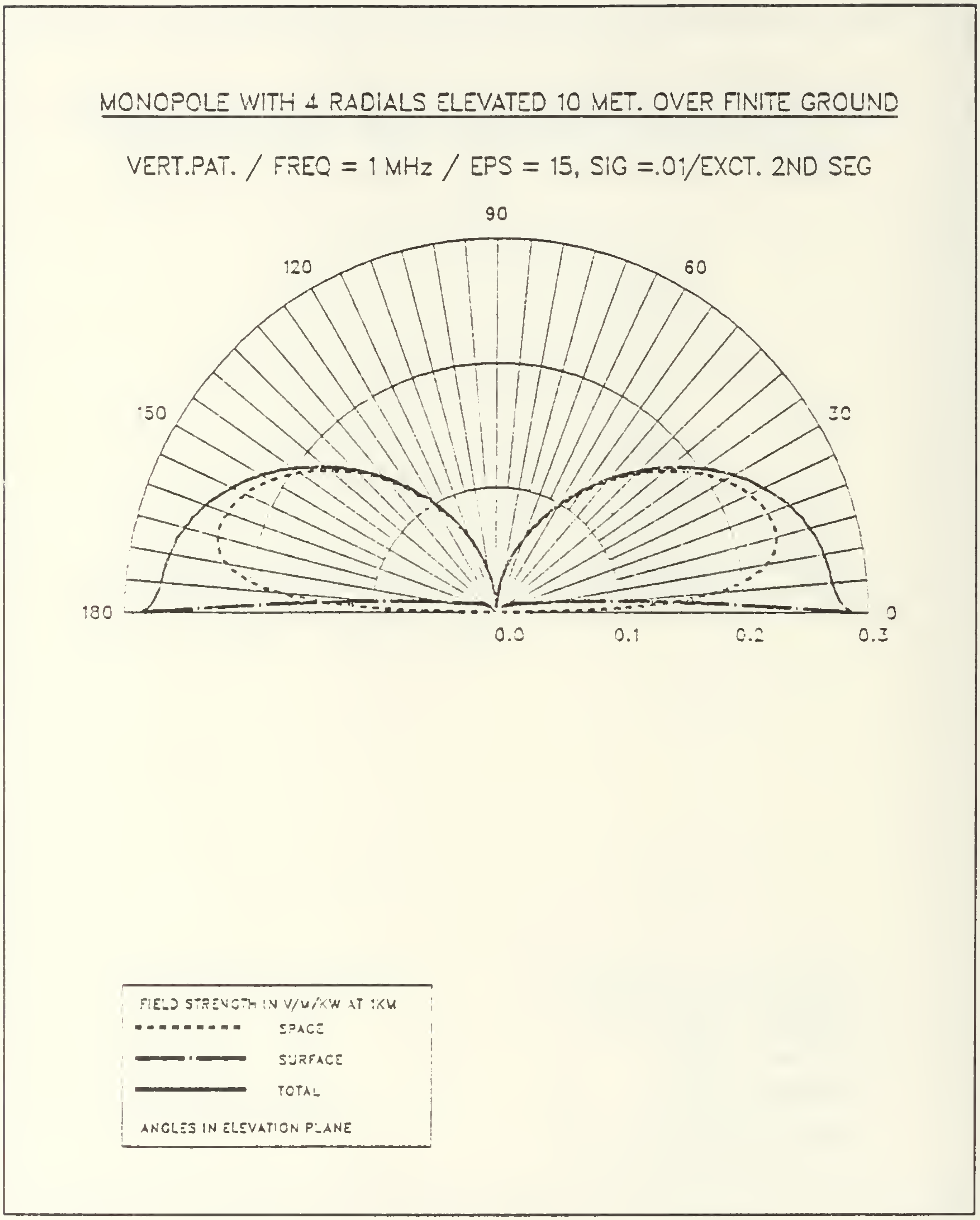

Figure C.18 Radiation Pattern - Monopole With 4 Radials Elevated 10 Meters Over Finite Ground Excitation Second Segment

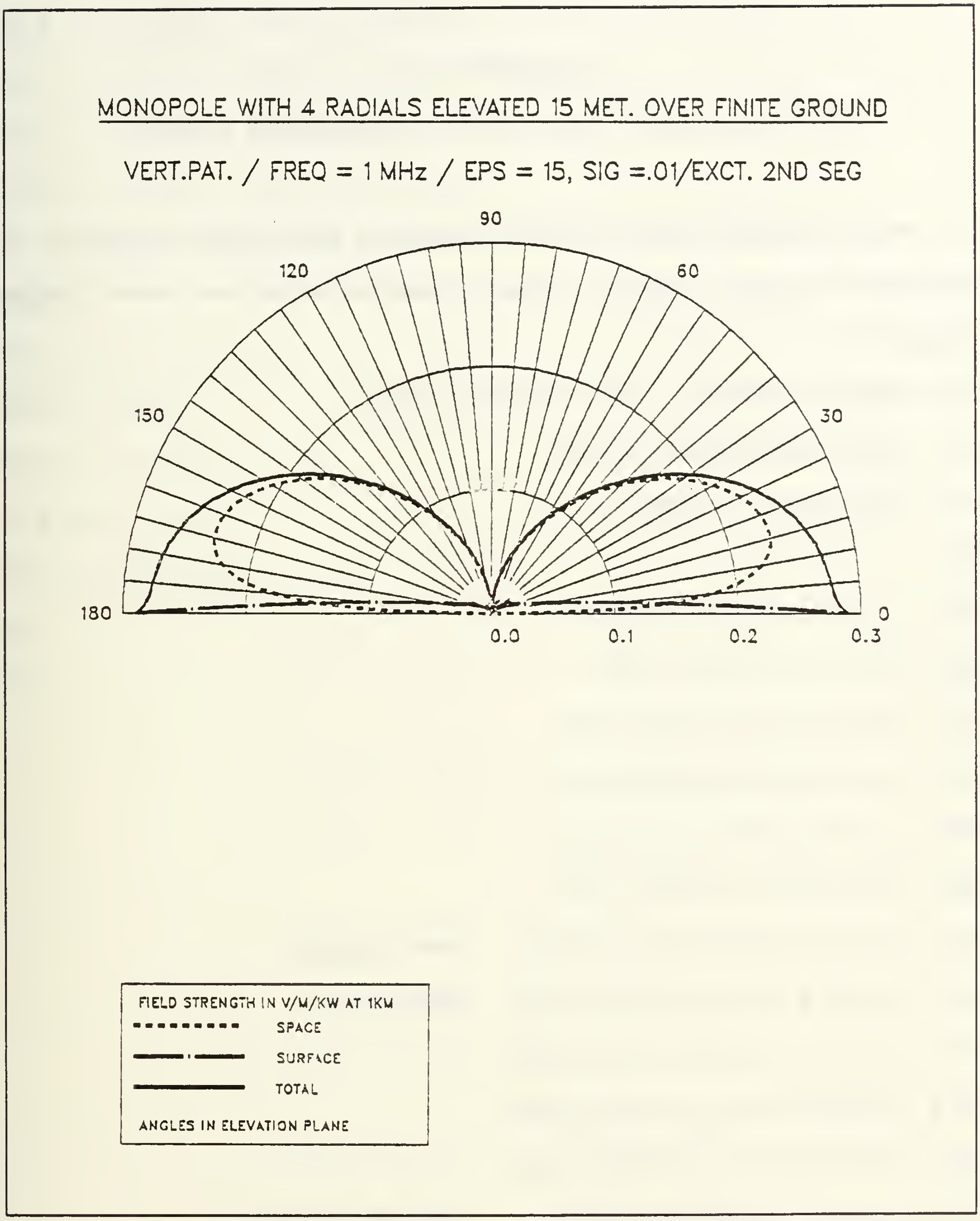

Figure C.19 Radiation Pattern - Monopole With 4 Radials Elevated 15 Meters Over Finite Ground Excitation Second Segment

APPENDIX D

INPUT DATA SETS USED FOR THE COMPUTER MODELS

1. The following data set was used to model the unipole antenna with four radial wires elevated 5 meters over finite ground.

```
CM  UNIPOLE ANTENNA OVER FINITE GROUND
CM  WITH FOUR RADIAL WIRES
CM  ELEVATION 5 METERS
CE
GW 1,2,0,0,0,0,0,2,0.003
GW 1,4,0,0,2,0,0,6,0.003
GW 1,10,0,0,6,0,0,16,0.003
GW 1,4,0,0,16,0,0,32,0.003
GW 1,2,0,0,32,0,0,53,0.003
GW 1,1,0,0,53,0,0,75,0.003
GW 2,1,0,0.9,75,0,0,75,0.003     TOP BRACKET
GW 3,2,0,0.9,1,0,0.9,21,0.003    FOLD WIRE
GW 3,2,0,0.9,21,0,0.9,41,0.003
GW 3,2,0,0.9,41,0,0.9,61,0.003
GW 3,2,0,0.9,61,0,0.9,75,0.003
GW 4,1,0,0,1,0,0.9,1,0.003 .     BOTTOM BRACKET
GM 4,2,0,0,120,0,0,0,002.004
GW 5,4,0,0,0,0,20,0,0.003        RADIAL WIRES
GW 5,3,0,20,0,0,40,0,0.003
```

```
GW 5,2,0,40,0,0,60,0,0.003

GW 5,1,0,60,0,0,75,0,0.003

GM 4,3,0,0,90,0,0,0,005.005

GM 0,0, 0,0,0, 0,0,5, 001.017

GW 18,1,0,0,0, 0,0,5, 0.003

GE 0

GN 2,0,0,0,15,0.01

FR 0,0,0,0,1

EX 0,4,1,0,296

EX 0,8,1,0,296

EX 0,12,1,0,296

XQ

EN
```

2. The following data set was used to model the unipole antenna with three radial wires elevated 5 meters over finite ground.

```
CM  UNIPOLE ANTENNA OVER FINITE GROUND
CM  WITH 3 RADIAL WIRES
CM  ELEVATION 5 METERS
CE
GW 1,2,0,0,0,0,0,2,0.003
GW 1,4,0,0,2,0,0,6,0.003
GW 1,10,0,0,6,0,0,16,0.003
GW 1,4,0,0,16,0,0,32,0.003
GW 1,2,0,0,32,0,0,53,0.003
GW 1,1,0,0,53,0,0,75,0.003
GW 2,1,0,0.9,75,0,0,75,0.003    TOP BRACKET
GW 3,2,0,0.9,1,0,0.9,21,0.003   FOLD WIRE
GW 3,2,0,0.9,21,0,0.9,41,0.003
GW 3,2,0,0.9,41,0,0.9,61,0.003
GW 3,2,0,0.9,61,0,0.9,75,0.003
GW 4,1,0,0,1,0,0.9,1,0.003      BOTTOM BRACKET
GM 4,2,0,0,120,0,0,0,002.004
GW 5,4,0,0,0,0,20,0,0.003       RADIAL WIRES
GW 5,3,0,20,0,0,40,0,0.003
GW 5,2,0,40,0,0,60,0,0.003
GW 5,1,0,60,0,0,75,0,0.003
GM 4,2,0,0,120,0,0,0,005.005
```

```
GM 0,0, 0,0,0, 0,0,5, 001.013

GW 18,1,0,0,0, 0,0,5, 0.003

GE 0

GN 2,0,0,0,15,0.01

FR 0,0,0,0,1

EX 0,4,1,0,296

EX 0,8,1,0,296

EX 0,12,1,0,296

XQ

EN
```

3. The following data set was used to model the unipole antenna with two radial wires elevated 5 meters over finite ground.

```
CM  UNIPOLE ANTENNA OVER FINITE GROUND
CM  WITH 2 RADIAL WIRES
CM  ELEVATION 5 METERS
CE
GW 1,2,0,0,0,0,0,2,0.003
GW 1,4,0,0,2,0,0,6,0.003
GW 1,10,0,0,6,0,0,16,0.003
GW 1,4,0,0,16,0,0,32,0.003
GW 1,2,0,0,32,0,0,53,0.003
GW 1,1,0,0,53,0,0,75,0.003
GW 2,1,0,0.9,75,0,0,75,0.003    TOP BRACKET
GW 3,2,0,0.9,1,0,0.9,21,0.003   FOLD WIRE
GW 3,2,0,0.9,21,0,0.9,41,0.003
GW 3,2,0,0.9,41,0,0.9,61,0.003
GW 3,2,0,0.9,61,0,0.9,75,0.003
GW 4,1,0,0,1,0,0.9,1,0.003      BOTTOM BRACKET
GM 4,2,0,0,120,0,0,0,002.004
GW 5,4,0,0,0,0,20,0,0.003       RADIAL WIRES
GW 5,3,0,20,0,0,40,0,0.003
GW 5,2,0,40,0,0,60,0,0.003
GW 5,1,0,60,0,0,75,0,0.003
GM 4,1,0,0,120,0,0,0,005.005
```

```
GM 0,0, 0,0,0, 0,0,5, 001.012

GW 18,1,0,0,0, 0,0,5, 0.003

GE 0

GN 2,0,0,0,15,0.01

FR 0,0,0,0,1

EX 0,4,1,0,305

EX 0,8,1,0,305

EX 0,12,1,0,305

XQ

EN
```

4. The following data set was used to model the unipole antenna with one radial wire elevated 5 meters over finite ground.

```
CM  UNIPOLE ANTENNA OVER FINITE GROUND
CM  WITH 1 RADIAL WIRE
CM  ELEVATION 5 METERS
CE
GW 1,2,0,0,0,0,0,2,0.003
GW 1,4,0,0,2,0,0,6,0.003
GW 1,10,0,0,6,0,0,16,0.003
GW 1,4,0,0,16,0,0,32,0.003
GW 1,2,0,0,32,0,0,53,0.003
GW 1,1,0,0,53,0,0,75,0.003
GW 2,1,0,0.9,75,0,0,75,0.003     TOP BRACKET
GW 3,2,0,0.9,1,0,0.9,21,0.003    FOLD WIRE
GW 3,2,0,0.9,21,0,0.9,41,0.003
GW 3,2,0,0.9,41,0,0.9,61,0.003
GW 3,2,0,0.9,61,0,0.9,75,0.003
GW 4,1,0,0,1,0,0.9,1,0.003       BOTTOM BRACKET
GM 4,2,0,0,120,0,0,0,002.004
GW 5,4,0,0,0,0,20,0,0.003        RADIAL WIRES
GW 5,3,0,20,0,0,40,0,0.003
GW 5,2,0,40,0,0,60,0,0.003
GW 5,1,0,60,0,0,75,0,0.003
GM 0,0, 0,0,0, 0,0,5, 001.012
```

```
GW 18,1,0,0,0, 0,0,5, 0.003
GE 0
GN 2,0,0,0,15,0.01
FR 0,0,0,0,1
EX 0,4,1,0,359
EX 0,8,1,0,359
EX 0,12,1,0,359
XQ
EN
```

5. The following data set was used to model the monopole antenna with four radial wires elevated 5 meters over finite ground.

```
CM MONOPOLE ANTENNA OVER FINITE GROUND
CM EXCITATION IN 1ST SEGMENT OF THE MONOPOLE
CM ELEVATION 5 METERS FROM THE GROUND
CE
GW 1,2,0,0,0,0,0,2,0.003
GW 1,4,0,0,2,0,0,6,0.003
GW 1,10,0,0,6,0,0,16,0.003
GW 1,4,0,0,16,0,0,32,0.003
GW 1,2,0,0,32,0,0,53,0.003
GW 1,1,0,0,53,0,0,75,0.003
GW 2,4,0,0,0,0,20,0,0.003         RADIAL WIRES
GW 2,3,0,20,0,0,40,0,0.003
GW 2,2,0,40,0,0,60,0,0.003
GW 2,1,0,60,0,0,75,0,0.003
GM 1,3,0,0,90,0,0,0,002.002
GM 0,0, 0,0,0, 0,0,5, 001.005
GW 6,3, 0,0,0, 0,0,5, 0.003
GE 0
GN 2,0,0,0,15,0.01
FR 0,0,0,0,1
EX 0,1,1,0,204
XQ
EN
```

6. **The following data set was used to model the typical AM broadcast antenna with 120 buried radial wires.**

```
CM 90 DEG. HIGH MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (EPS=15,SIG=.01,F=1.0)
CM 2)120 RADIAL ELEMENTS GROUND SCREEN LAMDA/4 LONG
CM 3)NO FENCE
CM 4)NO RING RADIATORS
CM USE PLOTRPVS TO PLOT ESP,ESUR,ETOT
CE
GW 1,1, 0,0,0, 0,0,4, 0.05            90 DEG HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05            90 DEG HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05           90 DEG HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05          90 DEG HIGH MONOPOLE
GR 0,120                              GND. SCRN. WITH 120 WIRES

GW 5,1, 0,0,0, 0,4.167,-.15, 0.05   SLOPING WIRE FOR GND.SCRN

GW 6,8, 0,4.167,-.15, 0,75,-.15, 0.05  HORIZONTAL GND.SCRN
GE -1
GN 2, 0, 0, 0, 15, .01                SOMMERFELD GROUND
FR 0,0,0,0, 1.00                      FREQ = 1 MHZ
EX 0,2,1,0,226.4                      FOR LOOP 1000W INP. POWER
EN
```

7. The following is a listing of file "NECGS RPCARDS" used as a part of all the data sets which model a structure over finite ground and are required to output the spacewave E field (PL3, RP0 cards), and the groundwave E field added to the spacewave E field (PL3 RP1 cards). Fortran code RP1 MAKER was used to produce PL3, RP1 cards.

```
PL 3,1,1
RP 0,90,1,1000, 90,180,-1,0, 1000
PL 3,1,1
RP 0,91,1,1000, 0,0,1,0, 1000
PL3,1,1
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04
PL3,1,1
RP1,1,1,1000,0.175E+02,0.180E+03,0.,0.,0.100E+04
PL3,1,1
RP1,1,1,1000,0.349E+02,0.180E+03,0.,0.,0.999E+03
PL3,1,1
RP1,1,1,1000,0.523E+02,0.180E+03,0.,0.,0.999E+03
PL3,1,1
RP1,1,1,1000,0.698E+02,0.180E+03,0.,0.,0.998E+03
PL3,1,1
RP1,1,1,1000,0.872E+02,0.180E+03,0.,0.,0.996E+03
PL3,1,1
RP1,1,1,1000,0.105E+03,0.180E+03,0.,0.,0.995E+03
PL3,1,1
```

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RP1,1,1,1000,0.122E+03,0.180E+03,0.,0.,0.993E+03

PL3,1,1

RP1,1,1,1000,0.139E+03,0.180E+03,0.,0.,0.990E+03

PL3,1,1

RP1,1,1,1000,0.156E+03,0.180E+03,0.,0.,0.988E+03

PL3,1,1

RP1,1,1,1000,0.174E+03,0.180E+03,0.,0.,0.985E+03

PL3,1,1

RP1,1,1,1000,0.191E+03,0.180E+03,0.,0.,0.982E+03

PL3,1,1

RP1,1,1,1000,0.208E+03,0.180E+03,0.,0.,0.978E+03

PL3,1,1

RP1,1,1,1000,0.225E+03,0.180E+03,0.,0.,0.974E+03

PL3,1,1

RP1,1,1,1000,0.242E+03,0.180E+03,0.,0.,0.970E+03

PL3,1,1

RP1,1,1,1000,0.259E+03,0.180E+03,0.,0.,0.966E+03

PL3,1,1

RP1,1,1,1000,0.276E+03,0.180E+03,0.,0.,0.961E+03

PL3,1,1

RP1,1,1,1000,0.292E+03,0.180E+03,0.,0.,0.956E+03

PL3,1,1

RP1,1,1,1000,0.309E+03,0.180E+03,0.,0.,0.951E+03

PL3,1,1

RP1,1,1,1000,0.326E+03,0.180E+03,0.,0.,0.946E+03

PL3,1,1
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RP1,1,1,1000,0.342E+03,0.180E+03,0.,0.,0.940E+03

PL3,1,1

RP1,1,1,1000,0.358E+03,0.180E+03,0.,0.,0.934E+03

PL3,1,1

RP1,1,1,1000,0.375E+03,0.180E+03,0.,0.,0.927E+03

PL3,1,1

RP1,1,1,1000,0.391E+03,0.180E+03,0.,0.,0.921E+03

PL3,1,1

RP1,1,1,1000,0.407E+03,0.180E+03,0.,0.,0.914E+03

PL3,1,1

RP1,1,1,1000,0.423E+03,0.180E+03,0.,0.,0.906E+03

PL3,1,1

RP1,1,1,1000,0.438E+03,0.180E+03,0.,0.,0.899E+03

PL3,1,1

RP1,1,1,1000,0.454E+03,0.180E+03,0.,0.,0.891E+03

PL3,1,1

RP1,1,1,1000,0.469E+03,0.180E+03,0.,0.,0.883E+03

PL3,1,1

RP1,1,1,1000,0.485E+03,0.180E+03,0.,0.,0.875E+03

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RP1,1,1,1000,0.500E+03,0.180E+03,0.,0.,0.866E+03

PL3,1,1

RP1,1,1,1000,0.515E+03,0.180E+03,0.,0.,0.857E+03

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RP1,1,1,1000,0.530E+03,0.180E+03,0.,0.,0.848E+03

PL3,1,1
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RP1,1,1,1000,0.545E+03,0.180E+03,0.,0.,0.839E+03

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RP1,1,1,1000,0.588E+03,0.180E+03,0.,0.,0.809E+03

PL3,1,1

RP1,1,1,1000,0.602E+03,0.180E+03,0.,0.,0.799E+03

PL3,1,1

RP1,1,1,1000,0.616E+03,0.180E+03,0.,0.,0.788E+03

PL3,1,1

RP1,1,1,1000,0.629E+03,0.180E+03,0.,0.,0.777E+03

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RP1,1,1,1000,0.643E+03,0.180E+03,0.,0.,0.766E+03

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RP1,1,1,1000,0.656E+03,0.180E+03,0.,0.,0.755E+03

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RP1,1,1,1000,0.669E+03,0.180E+03,0.,0.,0.743E+03

PL3,1,1

RP1,1,1,1000,0.682E+03,0.180E+03,0.,0.,0.731E+03

PL3,1,1

RP1,1,1,1000,0.695E+03,0.180E+03,0.,0.,0.719E+03

PL3,1,1

RP1,1,1,1000,0.707E+03,0.180E+03,0.,0.,0.707E+03

PL3,1,1
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RP1,1,1,1000,0.731E+03,0.180E+03,0.,0.,0.682E+03
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RP1,1,1,1000,0.743E+03,0.180E+03,0.,0.,0.669E+03
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RP1,1,1,1000,0.755E+03,0.180E+03,0.,0.,0.656E+03
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RP1,1,1,1000,0.766E+03,0.180E+03,0.,0.,0.643E+03
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RP1,1,1,1000,0.788E+03,0.180E+03,0.,0.,0.616E+03
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RP1,1,1,1000,0.848E+03,0.180E+03,0.,0.,0.530E+03
PL3,1,1
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RP1,1,1,1000,0.100E+04,0.000E+00,0.,0.,0.175E+02
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RP1,1,1,1000,0.999E+03,0.000E+00,0.,0.,0.349E+02
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RP1,1,1,1000,0.999E+03,0.000E+00,0.,0.,0.523E+02
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RP1,1,1,1000,0.998E+03,0.000E+00,0.,0.,0.698E+02
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RP1,1,1,1000,0.996E+03,0.000E+00,0.,0.,0.872E+02
PL3,1,1
RP1,1,1,1000,0.995E+03,0.000E+00,0.,0.,0.105E+03
PL3,1,1
RP1,1,1,1000,0.993E+03,0.000E+00,0.,0.,0.122E+03
PL3,1,1
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RP1,1,1,1000,0.982E+03,0.000E+00,0.,0.,0.191E+03

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RP1,1,1,1000,0.978E+03,0.000E+00,0.,0.,0.208E+03

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RP1,1,1,1000,0.974E+03,0.000E+00,0.,0.,0.225E+03

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RP1,1,1,1000,0.970E+03,0.000E+00,0.,0.,0.242E+03

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RP1,1,1,1000,0.966E+03,0.000E+00,0.,0.,0.259E+03

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RP1,1,1,1000,0.961E+03,0.000E+00,0.,0.,0.276E+03

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RP1,1,1,1000,0.956E+03,0.000E+00,0.,0.,0.292E+03

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RP1,1,1,1000,0.951E+03,0.000E+00,0.,0.,0.309E+03

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RP1,1,1,1000,0.946E+03,0.000E+00,0.,0.,0.326E+03

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RP1,1,1,1000,0.940E+03,0.000E+00,0.,0.,0.342E+03

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RP1,1,1,1000,0.921E+03,0.000E+00,0.,0.,0.391E+03
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RP1,1,1,1000,0.914E+03,0.000E+00,0.,0.,0.407E+03
PL3,1,1
RP1,1,1,1000,0.906E+03,0.000E+00,0.,0.,0.423E+03
PL3,1,1
RP1,1,1,1000,0.899E+03,0.000E+00,0.,0.,0.438E+03
PL3,1,1
RP1,1,1,1000,0.891E+03,0.000E+00,0.,0.,0.454E+03
PL3,1,1
RP1,1,1,1000,0.883E+03,0.000E+00,0.,0.,0.469E+03
PL3,1,1
RP1,1,1,1000,0.875E+03,0.000E+00,0.,0.,0.485E+03
PL3,1,1
RP1,1,1,1000,0.866E+03,0.000E+00,0.,0.,0.500E+03
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RP1,1,1,1000,0.857E+03,0.000E+00,0.,0.,0.515E+03
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RP1,1,1,1000,0.829E+03,0.000E+00,0.,0.,0.559E+03

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RP1,1,1,1000,0.766E+03,0.000E+00,0.,0.,0.643E+03

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RP1,1,1,1000,0.755E+03,0.000E+00,0.,0.,0.656E+03

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PL3,1,1

RP1,1,1,1000,0.719E+03,0.000E+00,0.,0.,0.695E+03

PL3,1,1

RP1,1,1,1000,0.707E+03,0.000E+00,0.,0.,0.707E+03

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RP1,1,1,1000,0.695E+03,0.000E+00,0.,0.,0.719E+03

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PL3,1,1

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RP1,1,1,1000,0.643E+03,0.000E+00,0.,0.,0.766E+03

PL3,1,1

RP1,1,1,1000,0.629E+03,0.000E+00,0.,0.,0.777E+03

PL3,1,1

RP1,1,1,1000,0.616E+03,0.000E+00,0.,0.,0.788E+03

PL3,1,1

RP1,1,1,1000,0.602E+03,0.000E+00,0.,0.,0.799E+03

PL3,1,1

RP1,1,1,1000,0.588E+03,0.000E+00,0.,0.,0.809E+03

PL3,1,1

RP1,1,1,1000,0.574E+03,0.000E+00,0.,0.,0.819E+03

PL3,1,1

RP1,1,1,1000,0.559E+03,0.000E+00,0.,0.,0.829E+03

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RP1,1,1,1000,0.530E+03,0.000E+00,0.,0.,0.848E+03

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RP1,1,1,1000,0.515E+03,0.000E+00,0.,0.,0.857E+03

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RP1,1,1,1000,0.500E+03,0.000E+00,0.,0.,0.866E+03

PL3,1,1

RP1,1,1,1000,0.485E+03,0.000E+00,0.,0.,0.875E+03

PL3,1,1

RP1,1,1,1000,0.469E+03,0.000E+00,0.,0.,0.883E+03

PL3,1,1

RP1,1,1,1000,0.454E+03,0.000E+00,0.,0.,0.891E+03

PL3,1,1

RP1,1,1,1000,0.438E+03,0.000E+00,0.,0.,0.899E+03

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RP1,1,1,1000,0.423E+03,0.000E+00,0.,0.,0.906E+03

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RP1,1,1,1000,0.407E+03,0.000E+00,0.,0.,0.914E+03

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RP1,1,1,1000,0.391E+03,0.000E+00,0.,0.,0.921E+03

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RP1,1,1,1000,0.309E+03,0.000E+00,0.,0.,0.951E+03

PL3,1,1
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RP1,1,1,1000,0.292E+03,0.000E+00,0.,0.,0.956E+03

PL3,1,1

RP1,1,1,1000,0.276E+03,0.000E+00,0.,0.,0.961E+03

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RP1,1,1,1000,0.259E+03,0.000E+00,0.,0.,0.966E+03

PL3,1,1

RP1,1,1,1000,0.242E+03,0.000E+00,0.,0.,0.970E+03

PL3,1,1

RP1,1,1,1000,0.225E+03,0.000E+00,0.,0.,0.974E+03

PL3,1,1

RP1,1,1,1000,0.208E+03,0.000E+00,0.,0.,0.978E+03

PL3,1,1

RP1,1,1,1000,0.191E+03,0.000E+00,0.,0.,0.982E+03

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RP1,1,1,1000,0.174E+03,0.000E+00,0.,0.,0.985E+03

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RP1,1,1,1000,0.156E+03,0.000E+00,0.,0.,0.988E+03

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RP1,1,1,1000,0.139E+03,0.000E+00,0.,0.,0.990E+03

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RP1,1,1,1000,0.122E+03,0.000E+00,0.,0.,0.993E+03

PL3,1,1

RP1,1,1,1000,0.105E+03,0.000E+00,0.,0.,0.995E+03

PL3,1,1

RP1,1,1,1000,0.872E+02,0.000E+00,0.,0.,0.996E+03

PL3,1,1
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```
RP1,1,1,1000,0.698E+02,0.000E+00,0.,0.,0.998E+03

PL3,1,1

RP1,1,1,1000,0.523E+02,0.000E+00,0.,0.,0.999E+03

PL3,1,1

RP1,1,1,1000,0.349E+02,0.000E+00,0.,0.,0.999E+03

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RP1,1,1,1000,0.175E+02,0.000E+00,0.,0.,0.100E+04

PL3,1,1

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PL 3,2,2

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LIST OF REFERENCES

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U. S. Naval Academy
Dept. of Elect. Eng.
Annapolis, MD 21402

11. Commander 1
USAISEIC ATTN: ASBI-STS (Janet McDonald)
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Lawrence Liv. Nat'l Lab.
PO Box 5504, L–156
Livermore, CA 94550

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185 Admiral Cochrane Dr.
Annapolis, MD 21402

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Hughes Aircraft CO/GD SYS
PO Box 3310
Fullerton, CA 92634

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PO Box 3 CL
Las Cruces, NM 88003

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K834628 Koutsouras
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